EDN®

THE DESIGN MAGAZINE OF THE ELECTRONICS INDUSTRY

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ANALOG DESIGN SPECIAL ISSUE

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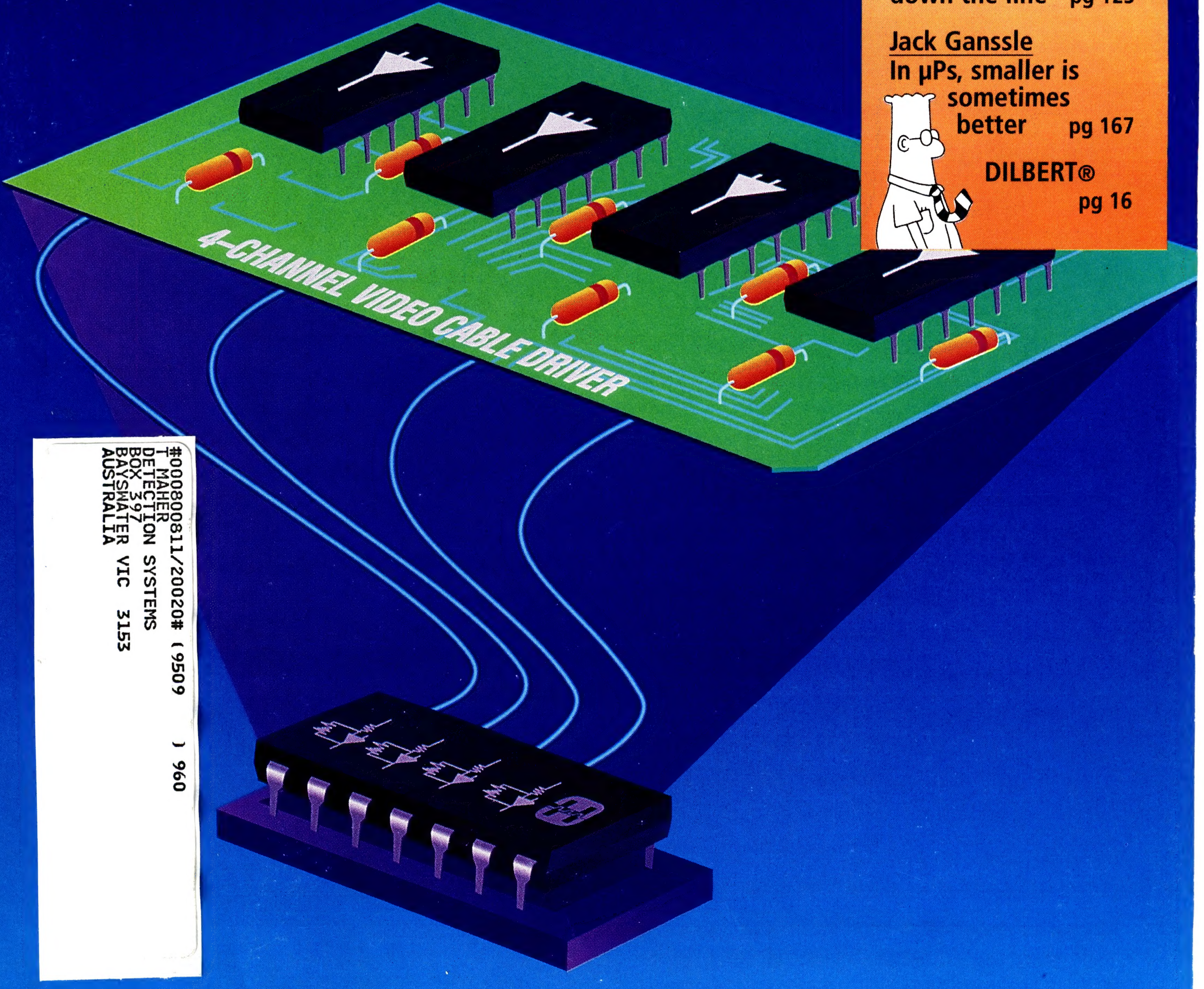

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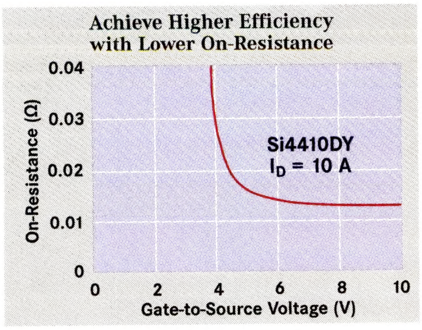

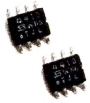

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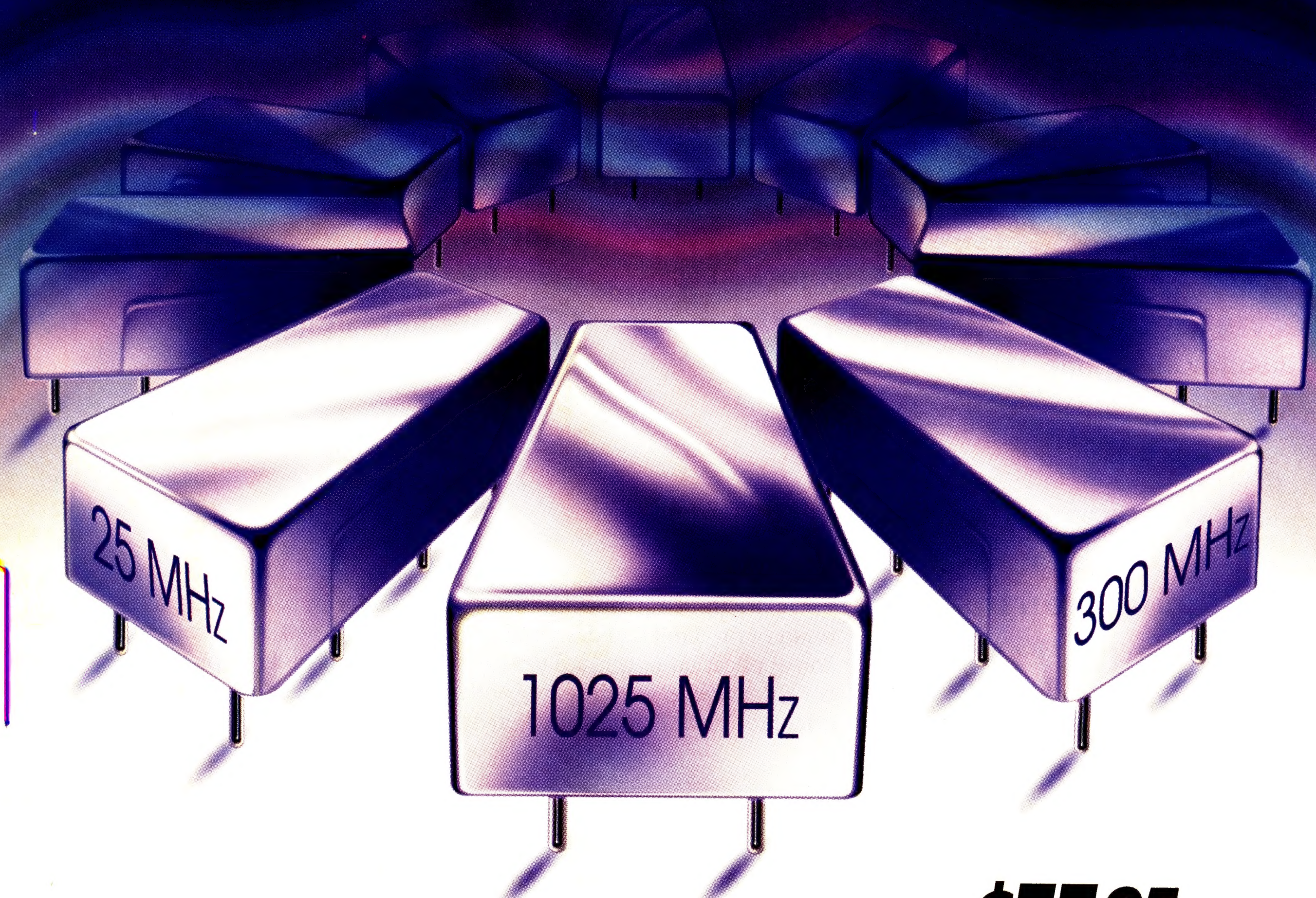

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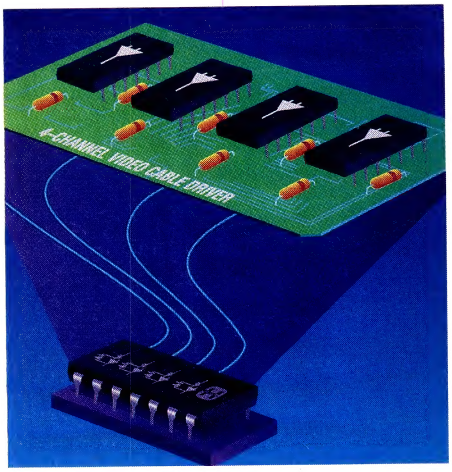
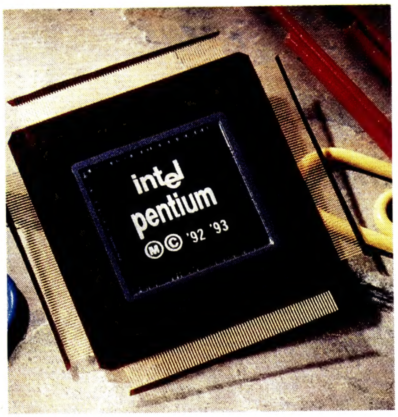


COVER STORY 38

Choosing an op amp

Photo courtesy Harris Semiconductor



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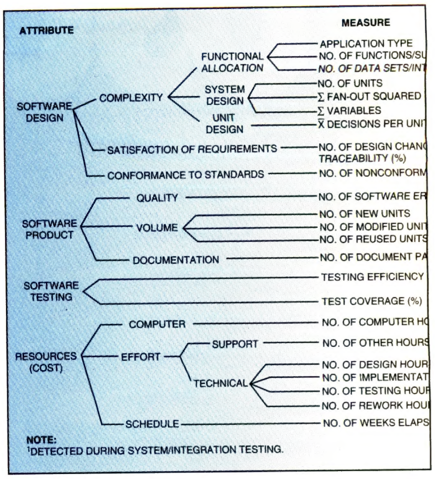


Software quality 75

EDN

DESIGN FEATURES

Choosing an op amp: it's no longer a trying task 38

There are more op amps available now than ever before. But, as a result of fundamental design improvements, focused specifications, and application-optimized devices, it's now a lot easier to pick one. For circuit designers, the parts' underlying process technology is secondary to their features and benefits.

—*Bill Schweber, Technical Editor*

More pins and less space beget new IC packaging 61

ICs keep sprouting more pins, yet dice must not grow, and packages have to shrink. The result will be new kinds of IC packages and new ways of connecting to dice—innovations that will profoundly affect upcoming product designs.—*Dan Strassberg, Senior Technical Editor*

Software quality: not an oxymoron 75

The economics of cost overruns and maintenance and the demands of ISO-9000 for European trade are forcing the software and embedded-systems industries to take a critical look at quality. Unfortunately, no quick answers are in sight.

—*Richard A Quinnell, Technical Editor*

Class D amplifiers provide high efficiency for audio systems 103

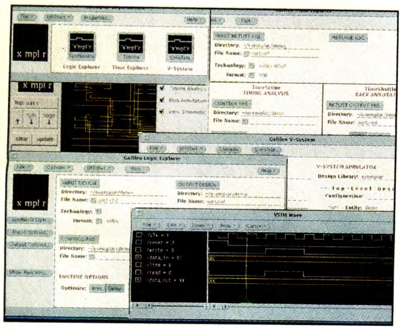
Advances in MOSFET technology and integrated half- and full-bridge predrivers now make class D amplifiers a practical alternative to linear amplifiers in many applications. The biggest benefit compared to more traditional amplifier topologies is high efficiency.

—*Jeffrey D Sherman, Harris Semiconductor*

Understanding a relay's operation can prevent trouble down the line 123

The venerable relay has undergone some changes in the past few years. Designers have supplemented conventional SSRs with optically coupled SSRs, challenging the familiar EMRs. You should understand the operation of these solid-state relays to get the best performance results.—*Doug Lionetti, Aromat Corp*

OUT IN FRONT



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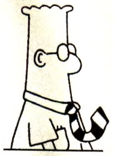

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In µPs, smaller is sometimes better 167

Derivatives of some of the earlier embedded CPUs still dominate the market.—*Jack Ganssle, Embedded-Systems Contributing Editor*

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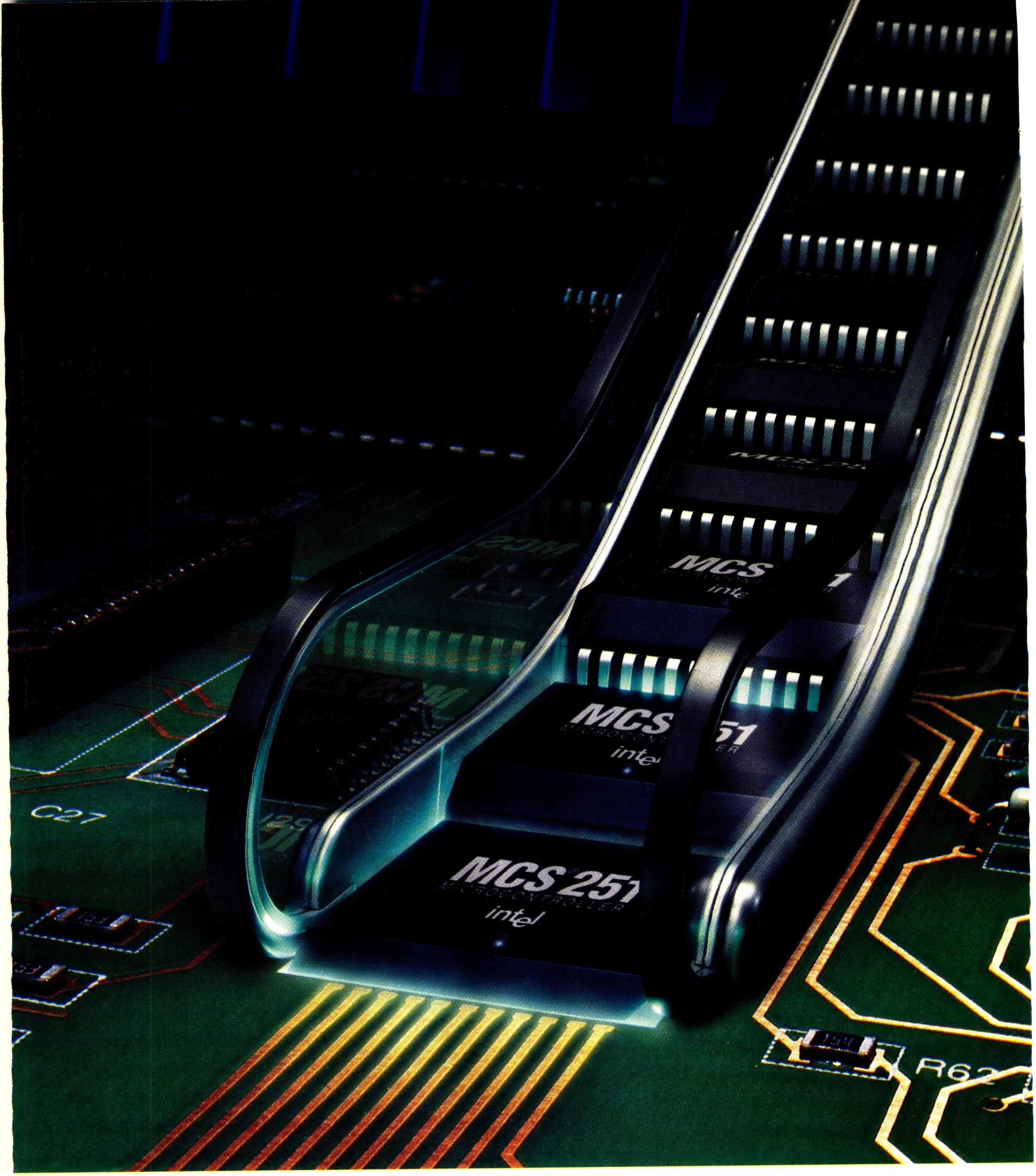

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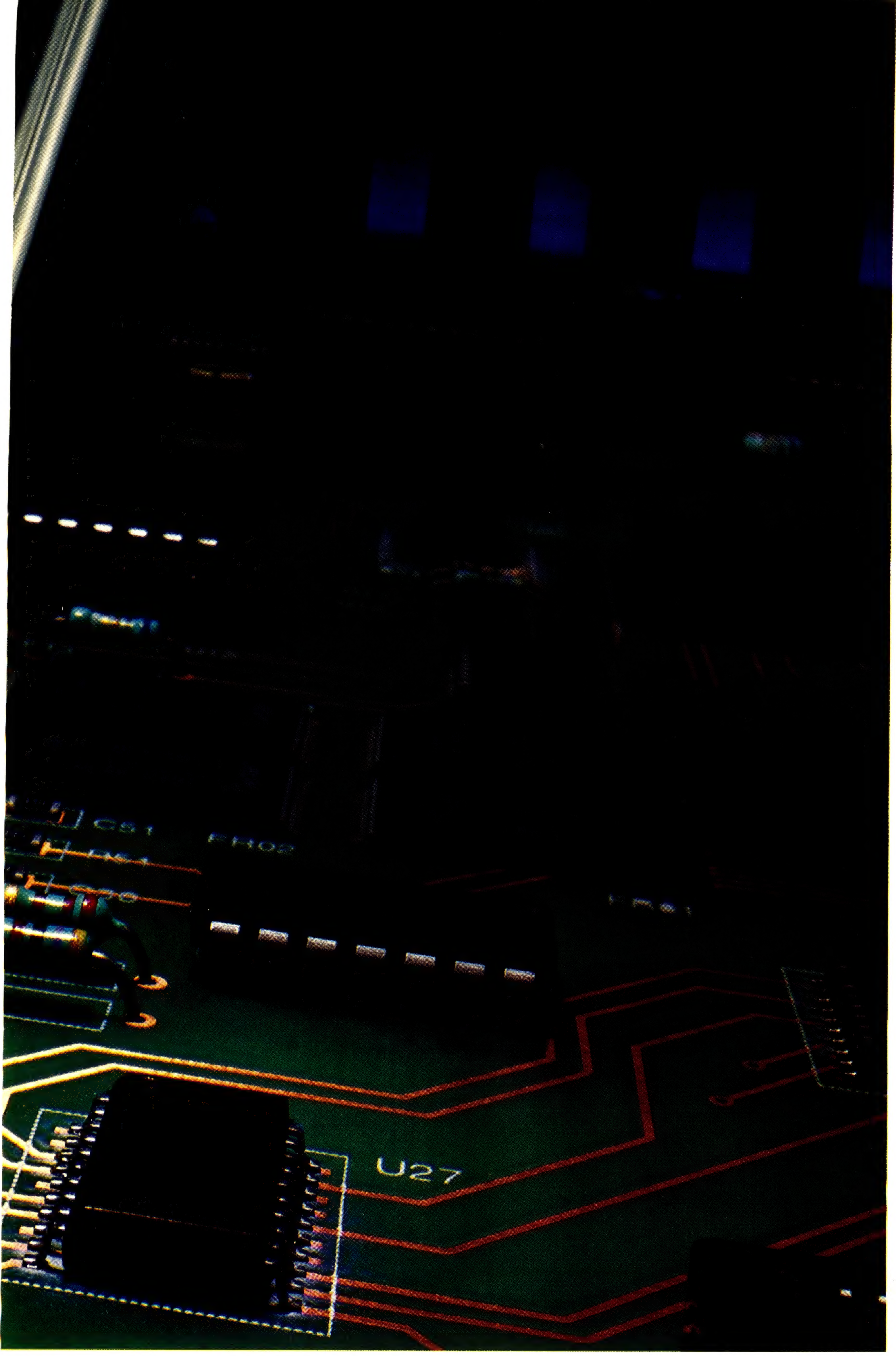

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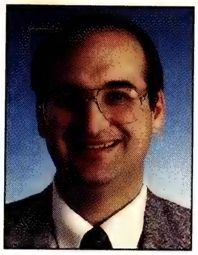

My family's March phone bill contained a big surprise: more than $200 in 900-number telephone charges. My wife asked why I had made so many expensive telephone calls to "INFOUSA." I told her that most 900-numbers are adult phone services and swore that I had not availed myself of these services. We had been the victims of fraud.

At first, I suspected that someone had used our telephone credit card. But, I called AT&T's 900-number service center ((800) 642-2708) and discovered that a caller can make these calls only directly from the phone number associated with the phone bill. Someone had apparently twice tapped into our home phone in February when no one was home. AT&T killed the charges and suggested that I ask my local phone company to block 900-number access and secure the network-interface boxes on the side of my house, a likely access point.

As we plunge into the widespread use of wireless technology, I urge you to design the proper safeguards into your products to prevent misuse by remote control.

My local phone provider, Nynex, was also helpful. It has blocked 900 service from my phone—no great loss, I assure you. Nynex told me that it would charge me about $60 to secure my network-interface boxes with cable ties, so I did that work myself.

However, my neighbor later pointed out another vulnerable spot in my home: my cordless phone. It provides wireless access to my phone line to anyone with a compatible transceiver. The range on my cordless-phone handset is about 50 ft, which I experimentally verified. A different transceiver might possibly do better, but, in any case, anyone standing near my home could place a call on my line if they wanted to and had the right equipment.

The lesson to learn here is that wireless technology, like all technology, is a two-edged sword. People will exploit the technology, unless we safeguard it, for illegal or unethical purposes. The simple analog wireless technology in my cordless phone contains no such safeguards and invites exploitation. Even my garage-door opener employs a security code to prevent unauthorized entry into my house. Security codes should be part of all cordless devices that could provide strangers with access to you, your loved ones, your property, your computer, or your bank account.

We often forget that there are people who are ready, willing, and able to misuse the fruits of our technological labors. As we plunge into the widespread use of wireless technology, I urge you to design the proper safeguards into your products to prevent misuse by remote control.

Steven H. Leibson

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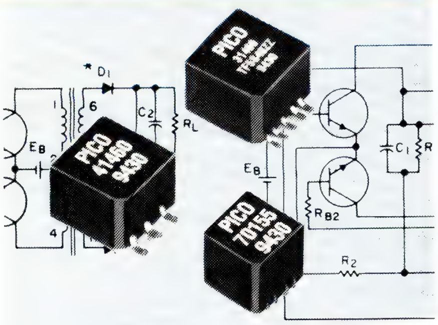

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CIRCLE NO. 144

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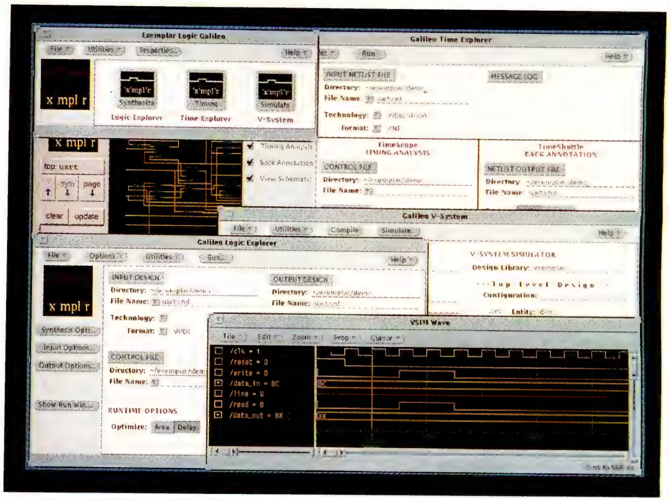
EDITED BY FRAN GRANVILLE

FPGA-TOOL VENDORS OFFER NEW CAPABILITIES

The market for programmable-logic software is buzzing, judging from the recent plethora of proclamations about new and enhanced field-programmable-gate-array (FPGA) design tools. During April and May, two electronic-design-automation companies and two FPGA companies announced software products to simplify FPGA design.

Exemplar Logic's new Galileo v3.0, an integrated, high-level design environment, combines synthesis, simulation, and static-timing verification. Galileo's synthesis supports both Verilog and VHDL. It uses "architecture-specific" logic optimization, meaning that it lets you optimize synthesized circuits for FPGA vendors, including Actel, Altera, AT&T, and Xilinx, and for vendors' device families. According to the company, this feature provides more efficient results than you can obtain from a generic synthesis tool.

The Galileo tool suite comprises the HDL Logic Explorer, Time Explorer, and V-System modules. HDL Logic Explorer synthesizes your VHDL or Verilog design description for a vendor's FPGA architecture. It then transfers the synthesized netlist to a third-party tool for placement and routing. Time Explorer provides interactive static-timing analysis to verify the synthesized design, along with a schematic window to show highlighted critical paths. It allows you to perform the timing analysis either directly on the synthesized netlist or on the circuit when it is back-annotated from a placement and routing tool. The V-System simulator, which comes with Time Explorer, performs gate-level design simulation.



The "architecture-specific" logic optimization in Exemplar's Galileo lets you target an FPGA family.

Prices for a Unix version for HP or Sun workstations start at $22,000. Prices for a PC version for Windows or Windows NT, which will be available this year, start at $12,000.

Another vendor, Xilinx, has also been busy. The company has added several features to its Xact tool suite. Xact 6.0 addresses FPGA management, design flow, and placement and routing. The software encompasses six new tools: a design manager, a flow engine, a floor planner, a timing analyzer, a hardware debugger, and a PROM formatter. The design manager and the flow engine help you implement and track your FPGA design. The timing analyzer performs a static-timing check on the design and allows you to compare multiple versions of a design. To accelerate design debugging, the hardware debugger lets you view activity of both internal and external signals during FPGA simulation.

Floor planning is becoming more important as densities for many high-performance FPGAs extend beyond 10,000 gates. Xilinx's FPGA floor planner works much like floor-planning tools for gate arrays and cell-based chips. It lets you graphically place critically timed logic elements on the chip and see what the resulting interconnect is among these and other logic

(continued on pg 16)

10-bit, 40M-sample/sec converter has comprehensive specs

Combining accuracy, low power, and 3.3V-interface compatibility, Harris' HI5703 A/D converter includes internal S/H circuitry and a test-enable option (three-state mode on outputs) for diagnostic and self-test modes. The converter suits medical (ultrasound), frame-grabber, and communications (digital-IF) applications. To cut power requirements in high-channel-count systems, the converter separates its digital output supply from its internal supply, allowing designers to use a 3.3V CMOS output interface while the device itself operates from a 5V supply.

Harris guarantees the converter's effective number of bits to be at least 8.3 (8.8 typ). The device features a 10-MHz input frequency, a 40M-sample/sec sampling rate, and 390-mW power consumption. Integral nonlinearity is 2 LSB max, and integral nonlinearity is 1 LSB max. The HI5703 can digitize a 2.5V p-p, 10-MHz input signal to 10-bit resolution with an S/N ratio of >51 dB. An open-loop S/H circuit enables the device to achieve a 250-MHz full-power input bandwidth.

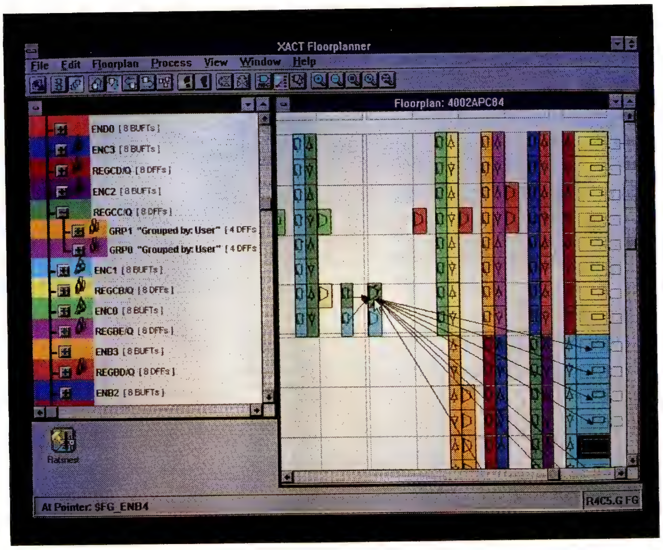
The converter comes in a 28-lead SOIC and costs $35 (1000). An evaluation board includes clock-driver circuitry, a reference-voltage generator, and selection of input drive circuitry (single-ended or differential, ac- or dc-coupled).—by Bill Schweber

Harris Semiconductor Corp, Melbourne, FL. (800) 442-7747, ext 7333. Circle No. 440

blocks. You can interactively try various component placements on the chip to optimize wiring of the logic blocks, which helps in choosing a final placement that maximizes the speed or density of the finished design. Current users of Xact can receive free upgrades to Version 6.0. New users pay $995 to $4595 for the PC version and $7995 for workstation versions.

QuickLogic also recently boarded the FPGA-tool bandwagon with the QuickTools 5.0 software package for designing with the company's pASIC 1 logic family. The package bundles version 5.0 of the company's SpDE tool with design-support utilities and third-party interface-support libraries.

QuickTools has two new capabilities to enhance FPGA designs: automatic buffer insertion for high fan-out signal paths and a secondary level of logic optimization that, according to QuickLogic, increases logic density an average of 12%. With SpDE 5.0, the company guarantees accurate signal-path timing when results are back-annotated to third-party simulators, including Cadence's Verilog-XL, Intergraph's VeriBest, Mentor Graphics' QuickSim, and SimuCad's Silos III. QuickLogic also claims automatic routing for all signal paths on the company's FPGA devices, even when the design uses all of the logic's cells and predefines all of the I/O pins.



With the Xact floor planner from Xilinx, you can interactively optimize the placement and routing of logic elements.

Current QuickTools users can receive free upgrades to 5.0. New users pay $995 for the PC version for Windows and Windows NT and $1995 for the HP and Sun workstation versions.

Yet another vendor, Mentor Graphics, has enhanced its FPGA Station tool suite by integrating the AutoLogic II synthesis tool into FPGA Station. The upgrade lets you synthesize and optimize VHDL or Verilog design descriptions into architecture-specific FPGA devices, including those from AT&T, LSI Logic, and Xilinx. AutoLogic II also offers enhanced programmable-logic libraries, which can cut an FPGA design's size.

Mentor Graphics has also integrated System Architect, which provides graphical design entry and management, *into* FPGA Station. Graphical input lets you specify your design in familiar ways, such as data-flow diagrams, Boolean equations, and state diagrams. Such specifications assist designers who commonly use schematic-based design techniques but need to migrate to top-down design for higher density FPGAs.

Prices of the FPGA Station tool suite for HP-PA and Sun workstations start at $27,300. Current customers can get free upgrades.—by Jim Lipman

Exemplar Logic, Alameda, CA. (415) 337-3700. **Circle No. 441**

Mentor Graphics, Wilsonville, OR. (503) 685-7000. **Circle No. 442**

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CIRCLE NO. 183

TOOL SUITE GENERATES CODE FROM SPECS

With the latest release of its BridgePoint tool kit, Objective Spectrum Inc now offers a complete tool kit for object-oriented analysis (OOA) and design of embedded-system software. BridgePoint 3.0 allows designers to follow the Shlaer-Mellor Method of OOA, automatically generating code from higher layer system design models. (For an explanation of the Shlaer-Mellor Method, see "Software quality: not an oxymoron" on pg 75.)

The Objective Spectrum tool kit has three BridgePoint components: Analyst, Sim, and Gen. BridgePoint Analyst, an OOA modeling tool, allows designers to capture their system requirements in a graphical model. The model describes all the functions the system must perform, as well as the information links between functions. BridgePoint Sim allows designers to exercise the model thus created to verify that the system design will perform as required. BridgePoint Gen, the most recent addition to the tool kit, automatically translates the model into executable source code using designer-specified templates. Together, the tools separate the design and coding tasks, leaving design to the engineers and automatically generating the corresponding code.

The tools run on Hewlett-Packard, Silicon Graphics, and Sun workstations. In addition, users of PC X-Windows can access server-based copies of the tools from a desktop PC. Single-copy costs, including a year of maintenance, for BridgePoint Analyst, Sim, and Gen are $6000, $10,000, and $15,000, respectively.

—by Richard A Quinnell

Objective Spectrum Inc, Cary, NC. (919) 460-1500. **Circle No. 445**

ICs transform PCs into multimedia machines

The NV1 (VRAM) and STG 2000 (DRAM) media accelerators from Nvidia integrate graphical-user-interface (GUI) acceleration, 3-D rendering, full-motion-video acceleration, wave-table synthesis, and a precision game port onto one chip. The accelerators support plug-and-play standards for Windows. You have a choice of direct glueless connection to the Peripheral Component Interconnect bus revision 2.0 or the VL-bus.

For GUI acceleration, the 2-D rendering engine supports graphics primitives, including bit-block line transfers. It executes all 256 Windows-defined raster operations at 8-, 15-, 24-, and 30-bit color depths. A line-drawing engine, which operates at 8-, 15-, 24-, and 30-bit/pixel color depths, frees the CPU from calculating error terms or determining independent and dependent axes. To draw an arbitrary line, you need only write the X1,Y1 and X2,Y2 coordinates to the media accelerator.

Hardware video scaling enables full-screen, true-color, motion-video playback. Hardware also integrates graphics and video for special effects, such as merging 3-D and video. The 3-D rendering engine offers bilinear and perspective-corrected texture mapping for rendering realistic images on flat and curved surfaces.

The accelerators combine audio and video on the same bus, simplifying synchronization. In addition, the accelerators incorporate a virtual-image interface, allowing multiple applications simultaneously to access the audio functions. The audio engine supports as many as 32 panned monophonic voices of 16-bit, 50-kHz wave-table synthesis. Because the wave-table samples reside in the PC's system memory, the media accelerators' hardware does not require additional ROM or RAM.

The NV1 and STG 2000 support 1 to 50 stereo digital-audio channels at 16 bits and at a 50-kHz sampling rate. The accelerators provide hardware A- and μ-Law compression and decompression. The devices also provide simultaneous digital emulation with general wave-table synthesis in DOS through an MPU-401 interface. The devices support tremolo, vibrato, and portamento. They also precisely control phase and delay to enable effects such as reverberation and 3-D audio.

The devices feature an eight-channel game port, which uses an A/D sampler with 13-bit resolution and a programmable sample rate. They use DMA to offload the CPU from the traditional game-port register polling. You can configure the game port as an IBM-standard game port to provide compatibility with DOS games.

An STG1732/1764 palette DAC features resolutions as high as 1280×1024 pixels at a 75-Hz refresh rate and supports 8-, 15-, 24-, and 30-bit color depths. The company manufactures the chips using SGS-Thomson's 0.5-μm, 3.3V processes, which meet ISO 9000 specifications.

Software drivers for the chip include Windows 3.1 and Video for Windows, Windows 95 and Video for Windows, Windows NT, and OS/2 version 2.1. The company also supplies a BIOS, utilities, installation, and setup. SGS-Thomson will market the STG 2000 DRAM version for $55 (OEM). Nvidia will market the NV 1 VRAM version for $70 (OEM).—by John Gallant

Nvidia, Sunnyvale, CA. (408) 720-6100.
Circle No. 446

SGS-Thomson Microelectronics, Carrollton, TX. (214) 466-6000.
Circle No. 447

Japanese space agency uses Sony equipment to study the earth. National Space Development of Japan (NASDA), the Japanese space agency, will use Sony Corp's data-recording and mass-storage systems to collect, process, and analyze earth data from space satellites. The equipment includes Sony's DIR 1000 series data recorders, DMS-700M and DMS-24 mass-storage systems, DFC-1800 series variable-rate buffers, and DFC-1500 SCSI-2 Fast computer interfaces.

Sony Corp, Montvale, NJ. (800) 472-7669.
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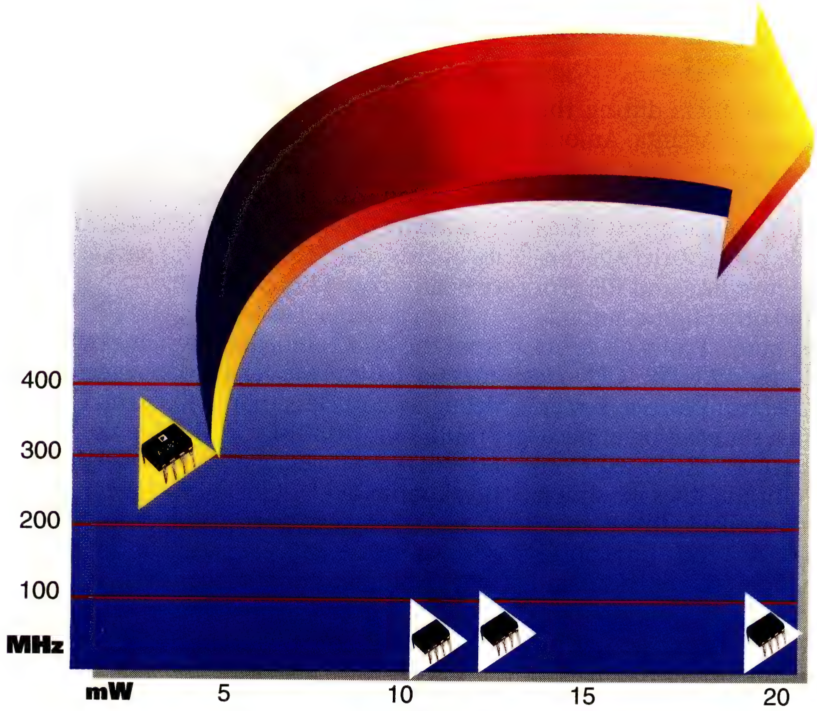

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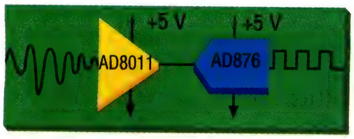

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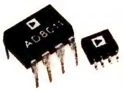

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NEWS FROM THE EMBEDDED SYSTEMS CONFERENCE

Network components, development system, and debugger debut

Companies introduced a range of products during the recent Embedded Systems Conference in Atlanta. Among them, the CENode Points family of network components from Intellon lets you easily incorporate the industry-standard, home-oriented Consumer Electronics Bus (CEBus) into your products. The CEBus works over a variety of connection media, including the ac power line and RF. (For more information on the CEBus and other home-automation buses, see "Home-automation buses: Protocols really hit home," *EDN*, April 13, 1995, pg 69.) The CENode Points protocol employs a spread-spectrum carrier. Power-line-based Connection Points with a simple 8-bit application interface cost less than $30 (1000). RF-based Connection Points and Application Point modules for simple sense-and-control functions will be available this year.

Motorola announced the MMDS1632 real-time modular development system, which handles the 68HC16 and 68300 μC families. The product comprises a station module, device-specific personality boards, package-specific personality and target boards, and appropriate emulation software. The system provides real-time emulation and real-time bus analysis through an integral 32k×96-bit state analyzer. The station module contains 1 Mbyte of emulation memory, 128 kbytes of fast-termination memory, and 4 kbytes of real-time read/write emulation memory. The module also comes with the Hiware software tool set and the company's MCU init software. Hiware includes a macro assembler, a linker, an assembly-language debugger, and C source-level debugger. The MCU init software simplifies register initialization, register editing, and code generation. All software runs under Microsoft Windows. The MMDS1632 costs $12,500. Microcontroller personality boards cost $500 to $1095; package-specific personality boards cost $595 to $2000.

The Periscope Co has migrated its hardware debugger from the PC to embedded systems by adding a 386EX μC adapter to the Model IV debugger card. The resulting debugger costs less than $4000 and can debug 80386EX, 80386SX, 80386DX, 80486DX, 80486DX2, and 80486DX4 processors. The Model IV can set memory breakpoints at eight location ranges in the first 16 Mbytes of address space; port breakpoints for as many as eight address ranges in I/O space; and set data breakpoints on byte, word, and double-word values. A pass counter and sequential trigger allow you to set more complex breakpoints.—Steven H Leibson

Intellon, Ocala, FL. (904) 237-7416. **Circle No. 452**

Motorola Advanced Microcontroller Division, Austin, TX. (800) 765-7795, ext 912. **Circle No. 453**

The Periscope Co Inc, Atlanta, GA. (404) 888-5335 **Circle No. 454**

ICE units come in modular form

Product releases at the recent Embedded Systems Conference East suggest that in-circuit emulators (ICEs) are adopting a modular architecture. At least three new products allow users to scale the ICE to match a project's cost and performance needs.

Embedded Support Tools Corp targets its visionICE at the Motorola 68300 family. The emulator's base unit ($3250) operates as a background-debug-mode emulator and provides essential services, such as reading registers and setting software breakpoints. The Event module ($6200) adds a real-time trace buffer and hardware comparators for eight-level if-then event triggering. The Net module ($2500) adds Ethernet communications to the system, allowing the ICE to handle remote debugging. The Mem module ($1600) adds as much as 4 Mbytes of overlay emulation memory. Users can add any or all of the modules to the base unit.

Emulation Technology Inc's ET-iC2000 emulator uses a base unit that offers ROM emulation for 16-bit memories and an ICE pod for 8- or 16-bit processors with clock speeds to 42 MHz. The pod contains all the processor-specific interfaces, allowing the base unit to work with as many as 160 processor types. An add-on trace buffer provides logic and software analysis, code coverage, and complex triggering capability. Prices begin at $4725 for the base unit, $1595 for pods, and $3130 to $3915 for the trace buffers.

Kontron Elektronik's DProbe386 handles the Intel 386EX using a bond-out chip for nonintrusive access to all registers, including hidden descriptors. The basic unit costs less than $5000 and provides emulation for all operating modes. Add-ons include overlay memory to 1.5 Mbytes and trace memory for 128k samples for as many as 96 channels.

The scalable nature of these emulators allows users to husband their tool budget by buying only the capability they need. Software developers, for instance, typically need only emulation for most of their debugging tasks. Hardware de-signers, on the other hand, often need trace capability. Project teams can thus acquire several sets of tools at minimal cost by acquiring several base units and fewer add-on modules. Project teams can then share the more expensive add-on capabilities without sharing the base tools.

—by Richard A Quinnell

Embedded Support Tools Corp, Canton, MA. (617) 828-5588. **Circle No. 449**

Emulation Technology Inc, Santa Clara, CA. (408) 982-0660. **Circle No. 450**

Kontron Elektronik Corp, Newport Beach, CA. (714) 851-1872. **Circle No. 451**

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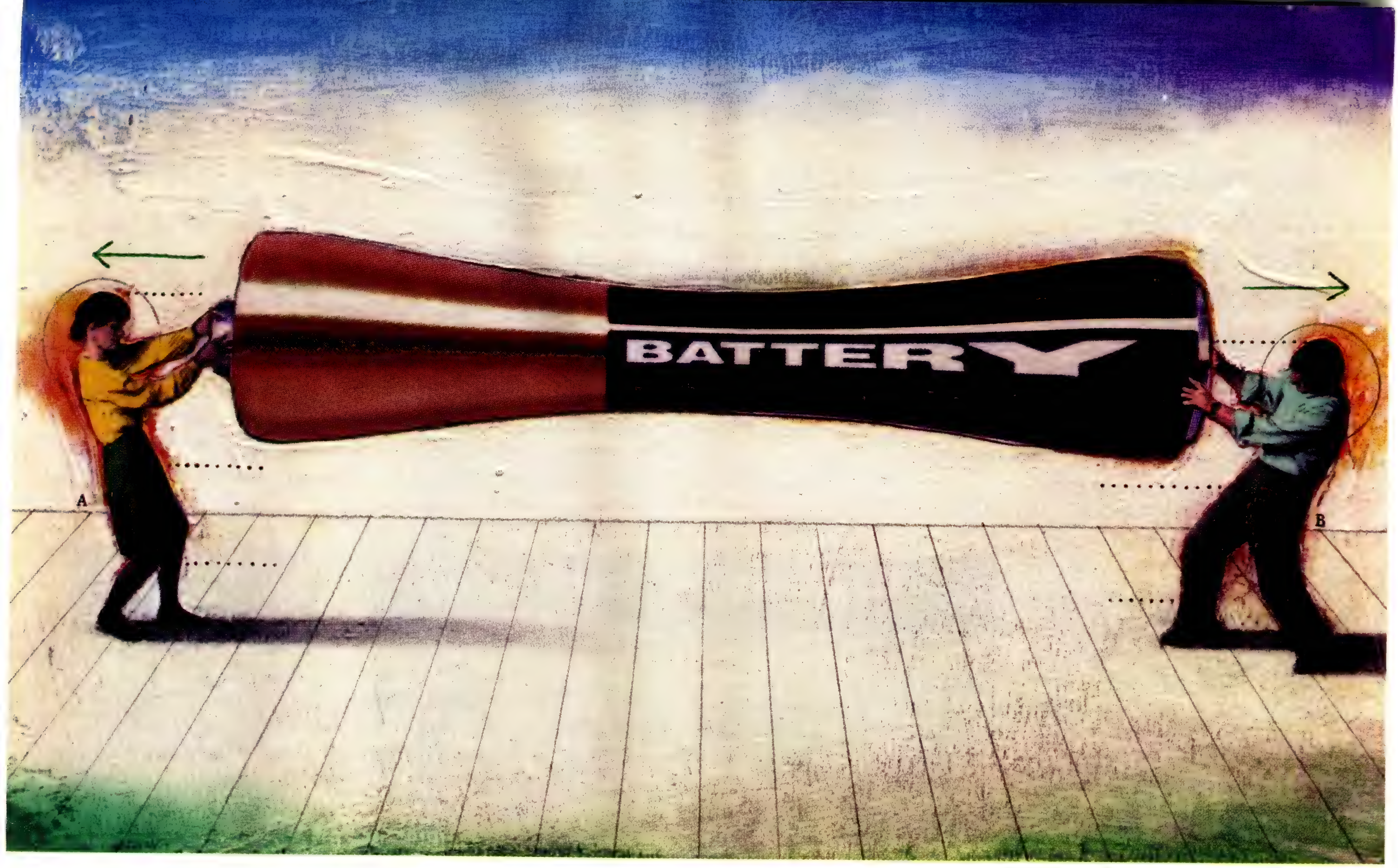

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Micron and Xilinx win In-Stat's 1995 Kachina awards

Micron Technology (Boise, ID) and Xilinx (San Jose, CA) won the 1995 Kachina awards from In-Stat at the 11th Annual Microelectronics Forum held at the Camelback Inn in Scottsdale, AZ. Hopi Indians carve the Kachinas, which are dolls that represent spirits. Each year, In-Stat presents Kachinas to the two best financially managed semiconductor companies (one with and one without a semiconductor-fabrication facility). This year, Micron Technology won the with-fab category, and Xilinx won the without-fab category. In-Stat rates contestants based on numerous characteristics, including net income as a percentage of sales, cost of sales, return on investment, inventory turnover, sales per employee, total-equity-to-total-assets ratio, and net operating profit as a percentage of sales.

—Steven H Leibson

In-Stat, Scottsdale, AZ. (602) 483-4440.

Circle No. 455

DSP chips suit wireless communications

Texas Instruments' two new DSP chips for digital cellular standards combine hard-wired functions with a specialized instruction set to implement Global System for Mobile (GSM), IS-54B, IS-136, personal-digital-cellular, and IS-95 standards. The TMS320C541 and TMS320C542 suit use in wireless communication terminals and base stations, respectively. Such applications include digital cellular phones, personal digital assistants, and wireless modems.

The C54x DSP members of TI's Low-power Enhanced Architecture DSP family operate at 2.7 or 5V and have three power-down modes. They feature 50-MIPS processing power and have a hard-wired Viterbi-decoder accelerator that reduces Viterbi "butterfly updates" to four instruction cycles for GSM-channel decoding. A single C54x chip implements all baseband DSP functions.

The C54x DSP chips use 12.7 MIPS of their 50 MIPS to implement full-rate GSM functions. The remaining millions of instructions/sec allow the DSP device to handle many tasks ASICs or microcontrollers traditionally handle, lower-

(continued on pg 26)

CALENDAR OF UPCOMING EVENTS . . .

June 6 to 8
TechNet '95, Washington, focuses on communications, electronics, intelligence, imaging, and information systems. The program has three tracks: "Tech Transfer" explores how the government, military, and private industry are collaborating to remain competitive. "Technology Solutions" uses real-life cases to explain approaches to technological changes. "Imaging '95," which requires separate registration, details how imaging is helping to re-engineer business and government. Armed Forces Communications and Electronics Association, Fairfax, VA. (800) 336-4583.

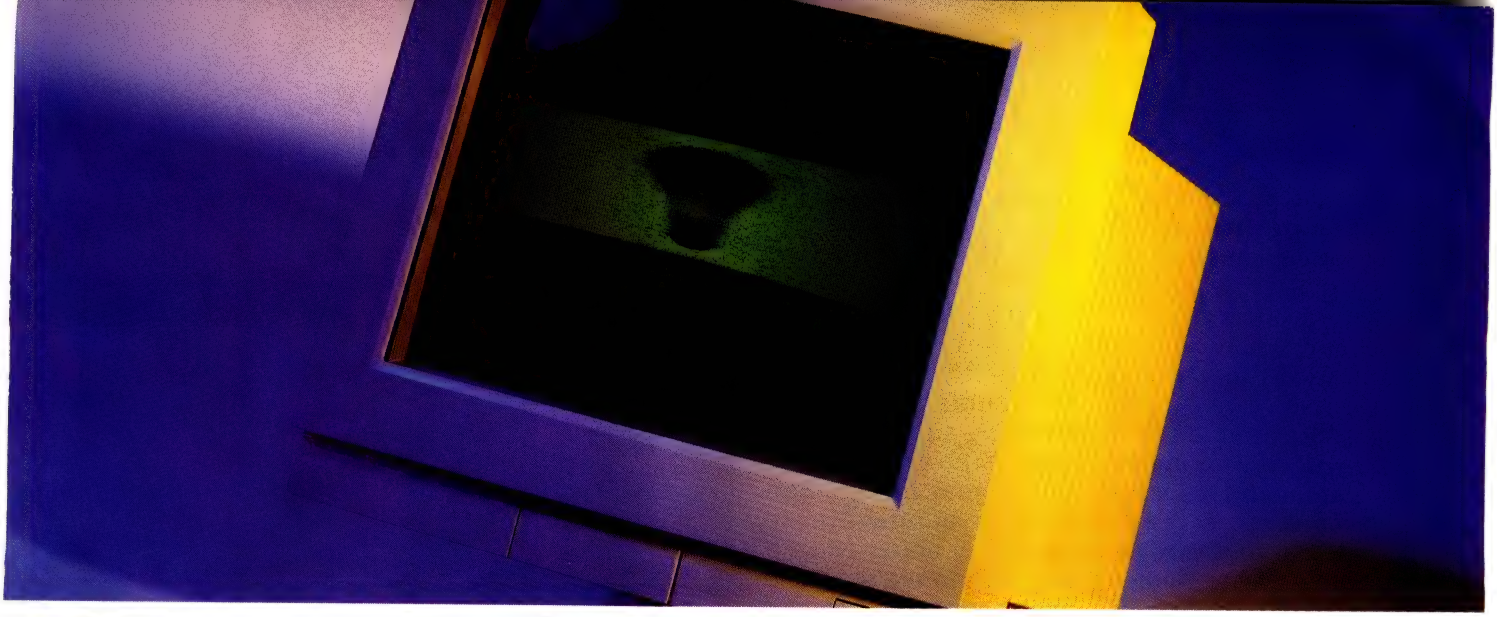
June 6 to 8
Medical Design and Manufacturing East, New York, offers 26 sessions, including sessions on the Food and Drug Administration's Good Manufacturing Practices. The conference includes an exhibition of 750 suppliers to the medical-product manufacturing industry. Canon Communications, Santa Monica, CA. (310) 392-5509.

June 18 to 22
IEEE International Conference on Communications, Seattle, offers tutorials on communications and networking topics, papers on current trends, and exhibits. IEEE, Seattle, WA. (206) 616-1596.

June 20 to 21
Malaysia Electronic Business Summit '95, Kuala Lumpur, Malaysia, examines topics and trends in the Malaysian electronics community, including business opportunities resulting from the convergence of computers, telecommunications, and broadcasting technology; business opportunities and the future of the Malaysian electronics industry; and technology issues and concerns. Reed Exhibition Co, Kuala Lumpur, Malaysia. (60) 03-254 1544.

June 21 to 23, 1995
Electro '95, Boston. This three-day electronics event has tutorials, sessions, more than 600 exhibit booths, and a new-product showcase. Sponsored by the IEEE and the Electronics Representatives Association. (800) 223-7126.

June 27 to 28, 1995
VMIC Conference, Santa Clara, CA, covers conductor and dielectric systems and parasitic and noise evaluations. Dr Thomas Wade, University of South Florida, Tampa, FL. (813) 974-4779.



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SWITCHING DIODES	*SOT-23*	*SC-70/SOT323*	*SC-59*	*SOD-123*	*KEY TRAIT*
SINGLE	*MMBD1000LT1*	*MMBD2000T1*	*MMBD3000T1*	*MMSD1000T1*	*LEAKAGE ≤ 500PA*
DUAL COMMON A.	*MMBD1005LT1*	*MMBD2005T1*	*MMBD3005T1*	—	*LEAKAGE ≤ 500PA*
DUAL COMMON C.	*MMBD1010LT1*	*MMBD2010T1*	*MMBD3010T1*	—	*LEAKAGE ≤ 500PA*
BIPOLAR					
PNP TRANSISTOR	*MMBT1010LT1*	—	*MSD1010T1*	—	*VCE(SAT) ≤ 100MV*
SIGNAL HDTMOS					
N-CHANNEL	*MMBF0201NLT1*	—	—	—	$rDS_{(on)} \leq 1\Omega$
P-CHANNEL	*MMBF0202PLT1*	—	—	—	$rDS_{(on)} \leq 1.4\Omega$

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[1] 1/50 our standard MMBD914LT1

[2] specified @ 76% of our standard MMBTA56LT1 @ 100mA Ic

[3] e.g., our N Channel SOT-23, specified @ 20% of our standard MMBF170LT1

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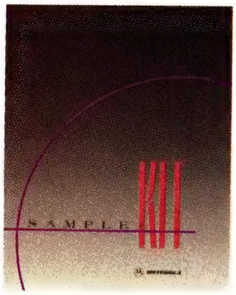

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ing overall system cost.

The chips allow efficient implementation of code-excited linear-predictive vocoders and other key digital communication functions. TI also lets you create a custom device around the C54x DSP core for more integration and reduced chip count, power dissipation, and cost. Customizable DSP technology allows the single-chip integration of the C54x core with microcontroller cores, additional memory, peripherals, and logic gates.

TI is also licensing full-rate GSM software modules that run on C451 and C452 chips and comply with the European Telecommunications Standards Institute specifications. The modules perform voice coding and decoding, demodulation, encryption, channel coding and decoding, and interrupt handling and control for GSM systems.

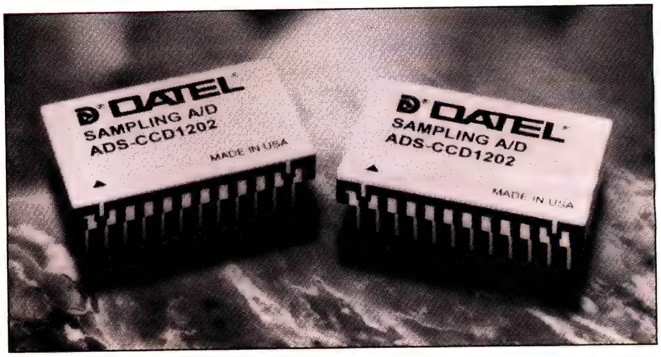
The C541 has 28k words of ROM and 5k words of RAM on chip, and the C542, which includes a host-interface and buffered serial ports, and features 2k words of ROM and 10k words of RAM. The C541 costs $23 (250,000) and is available now. The C542 costs $26 (250,000). It is available for sampling now and will enter volume production in the fourth quarter.

—by John Gallant

Texas Instruments Inc, Denver, CO. (800) 477-8924, ext 4500.

Circle No. 456

A/D converter is optimized for imaging applications



Datel's ADS-CCD1202 A/D converter balances wide and narrow bandwidths in CCD-based imaging applications.

Datel's ADS-CCD1202 A/D converter balances conflicting converter constraints in CCD-based imaging applications: wide bandwidth to maintain signal fidelity and narrow bandwidth to minimize noise. The 12-bit, 2M-sample/sec flash-architecture converter includes an S/H amplifier, a reference, timing and control logic, and error-correction circuitry in a 24-pin, dual-width DIP. The converter requires 5V and either ±15 or ±12V supplies; power consumption is 1.95W max.

A single clock edge triggers conversion. Due to the converter's architecture, the device has no internal pipeline delay. Maximum differential nonlinearity is ±0.45 LSB, rms noise is 600 μV (1/4 LSB), and S/N ratio is –71 dB or better. Overload time—critical in imaging applications—is 400 nsec. Price for a 0 to 70°C version is $199 (100); versions with full MIL-STD-883 qualification are also available.—by Bill Schweber

Datel Inc, Mansfield, MA. (508) 339-3000, ext 227. **Circle No. 457**

HIGH-SCHOOL STUDENTS INVENT DEVICES TO AID PHYSICALLY CHALLENGED

An automatic telephone dialer calls 911. The operator at the emergency dispatching center hears this message: "This is a recording. There is a fire in the Jones residence at 123 Pleasant Lane. This house is occupied by a physically challenged person who is unable to dial the phone…" Three senior high-school students from Keefe Technical High School in Framingham, MA, recently won $2500 scholarships to Northeastern University in Boston for designing and constructing the less-than-$200 system that placed the call. Northeastern's School of Engineering Technology holds the competition each spring to give the students a taste of what product development and inventing are all about—and to attract the best and brightest vocational-school graduates to its degree-granting cooperative programs in engineering technology. The winning team was one of eight from Boston-area vocational high schools that competed for the scholarships. Each team included three juniors or seniors.

Among projects that garnered honorable mentions in the competition are a system of flashing LEDs mounted along the baseboards of rooms and hallways to guide a person crawling away from a source of smoke or heat and toward a safe exit; an overhead garage-door opener modified to open an ordinary hinged door to admit a person in a wheelchair; and a modified version of a special combination crutch, ski, and ski pole for one-legged skiers.

The judges assigned points based on how practical an idea was, how well the team executed the design and documented it in a report, how well the team members understood the underlying technology, and how well they were able to explain what they did—and why they did it. Although most of the young inventors have a way to go before they truly understand what product development is all about, their enthusiasm and pride are impressive.—by Dan Strassberg

Circle No. 458

The Competitive Edge in a Changing Marketplace

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CIRCLE NO. 180

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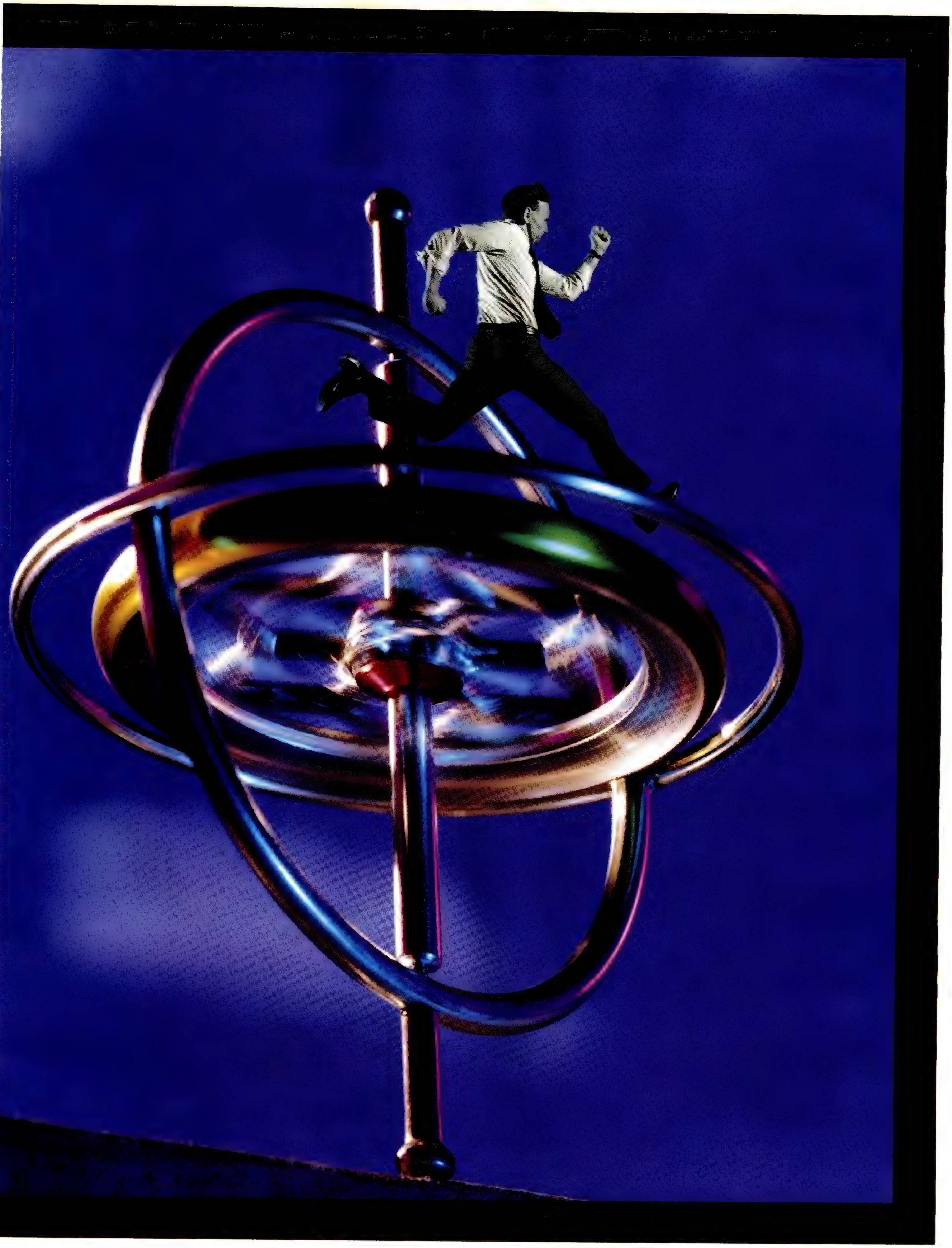

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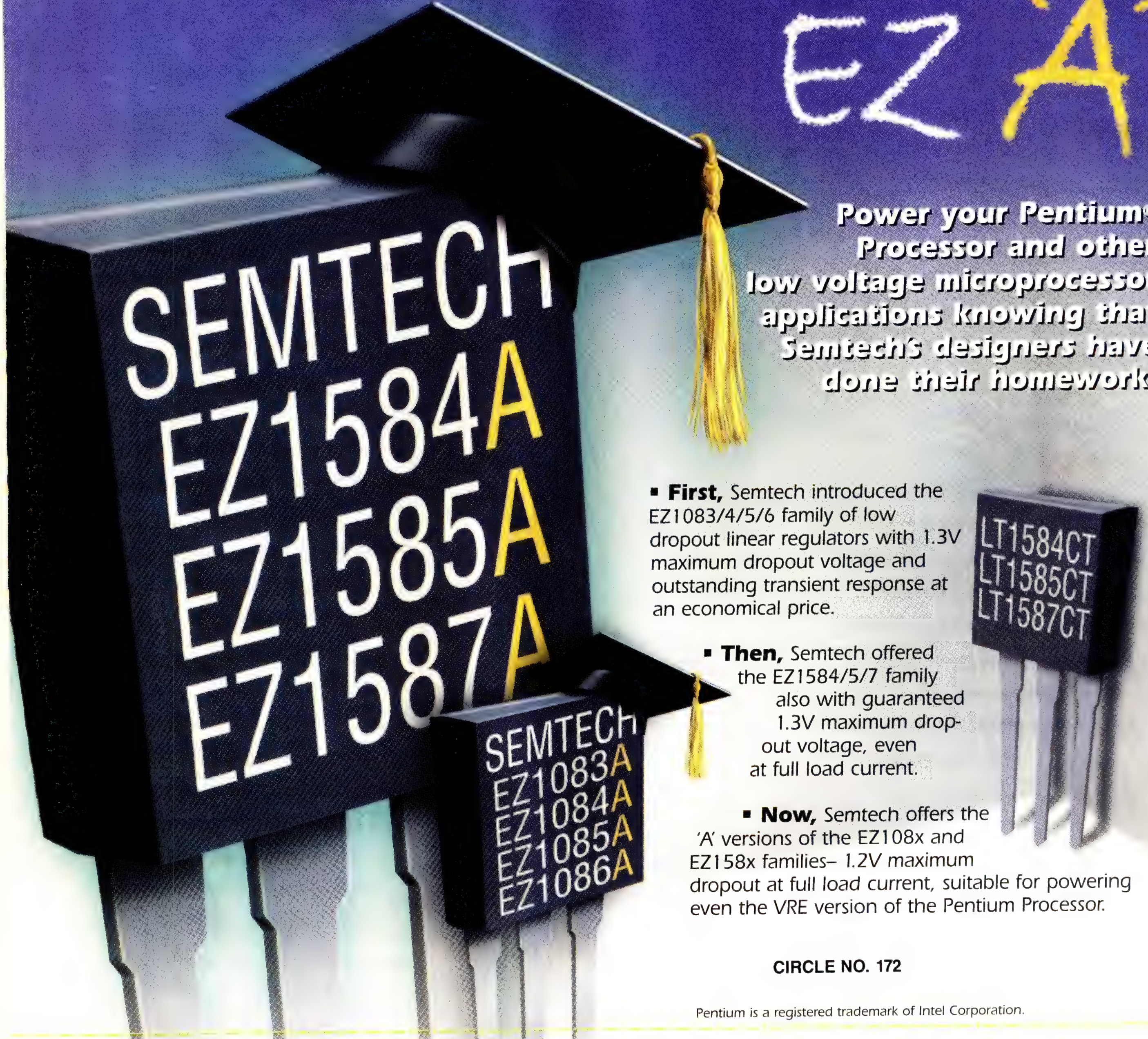

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Add to PCI bus article

"Tools offer a smooth ride on the PCI bus" (*EDN*, March 30, 1995, pg 32) omitted the following PCI development tools from Catalyst Enterprises Inc (San Jose, CA): Passive PCI Extender, PCIPX-64 ($79), Active PCI Extender, PCI532 and PCI332 (5 and 3.3V, respectively ($345)), PCI Mezzanine Extender, PMC2PCI-64 ($395), and, for 64- and 32-bit cards, the Active PCI Extender, PCIX-6432-5 ($365).

You can reach Catalyst Enterprises at (408) 268-4145.

"Ingineer" has his say

Because my filing system is more like that described by Dennis Feucht *before* he built his dream lab in Pennsylvannia (*EDN* Signals & Noise, March 16, 1995, pg 25), I am just getting around to reading that issue of *EDN*. I related strongly with Jim Williams' original article about building a home lab with used test equipment—and have been doing so for the past 40 years.

Rich Pagnusat, another correspondent in the same issue, took a different view—that all work and no play leads to mental burnout. He probably has an engineering degree (my degree is in physics) and may be a registered professional engineer, but anyone who regards engineering as work isn't really an engineer. Most "real" engineers, if blessed to have a job doing "real" engineering, are being paid to do what they would do for free. Thirty years of working at regular engineering jobs was satisfying. But only as an aging freelance electronic "ingineer" (it's not legal for me to describe my title as engineer) working sometimes as a consultant, sometimes through a job shop, and sometimes not at all, have I really found out how much fun life can be.

S Brown Pulliam,
Bedford, MA

Don't bury it yet

Steve Leibson's editorial "Revisiting Decade 90: packaging" (*EDN*, Feb 16, 1995, pg 11), has particular meaning to us at Pico Systems Inc. Pico is the descendant of Mosaic Systems, the originator of electrically programmable multichip-module (MCM) technology. (Mosaic referred to the technology as programmable silicon circuit board (PSCB).)

Some time ago, the Environmental Research Institute of Michigan (ERIM) contracted Mosaic Systems for miniaturization of a number of boards to be developed under the US Army's Advanced Target and Cueing Recognition Engineer (ATCURE) program. Mosaic Systems went bankrupt in the early '90s, and ERIM purchased the rights to the PSCB technology.

In late summer of 1993, the ATCURE program was successfully completed. A major element of the final system was a miniaturized version of the system's pipeline-processing module (PPM).

The PPM makes use of two substrate sizes: four instances of a 30×30-mm

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CIRCLE NO. 96

substrate mounted on a 100-mm substrate in daughtercard/motherboard fashion. The module contains approximately 70 ICs: ASICs, EEPROMs, FIFO buffers, buffer/transceivers, clock drivers, field-programmable gate arrays, etc. The wafer-scale MCM was mounted on a SEM-E frame and placed in a ¾ ATR enclosure. The SEM-E version of the PPM is entirely "swappable" with any full-size board implementation of the PPM in the ATCURE system.

The PSCB technology continued to evolve while part of ERIM. We have just concluded testing of an ECL circuit implemented on Pico's 30×30-mm substrate. The circuit contained the worst possible routing for a clock net and still performed at legitimate ECL levels while running at 200 MHz. And, Pico's next-generation substrates will be at least 2 to 3× faster than our current substrate design.

Pico Systems represents the phoenix of the Mosaic Systems technology you mentioned in your editorial. The technology is far from buried. More than ever, the product is uniquely suited to act as an "enabling technology" for the MCM industry.

Robert Miller
Pico Systems Inc
Ann Arbor, MI

SuperCon contact

In "Out In Front" (*EDN*, March 30, 1995, pg 14), we listed an incorrect phone number for obtaining papers from Design SuperCon. To obtain the proceedings from the conference, contact MP Associates (Boulder, CO) at (303) 530-4562.

Terms of agreement

In "High-density flash memory: now a practical option for system design" (*EDN*, February 16, 1995, pg 53), the section regarding AND and DINOR flash technology contains an inaccuracy. The article makes it appear that Hitachi is working alone on these technologies when, in fact, in January of 1994, Mitsubishi announced an agreement with Hitachi for codeveloping DINOR and AND flash memories.

Mitsubishi, not Hitachi, will be the first to deliver a 16-Mbyte DINOR flash device later this year. Mitsubishi is driving DINOR technology development; Hitachi is driving AND. Under terms of the agreement, the two companies will produce each other's DINOR and AND devices, combining resources to shorten the development cycle, reduce costs, and provide second-source products.

Bob Bell and John Hansen
Mitsubishi Electronics America Inc
Sunnyvale, CA

Sound off

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Mixed-Signal Peripherals	**Analogue Interface Circuits** • 14- or 16-bit A/D and D/A • Up to 80 dB SNR • Programmable sampling rate up to 32 kHz	**Voice-Band Audio Circuits** • Select 8-bit companded or 13-bit linear conversion • Programmable sampling rate up to 24 kHz • Compatible with CCITT standards	**Sigma-Delta CODECs** • 16- or 18-bit A/D and D/A • Up to 97 dB SNR • Programmable sampling rate up to 48 kHz • Stereo audio

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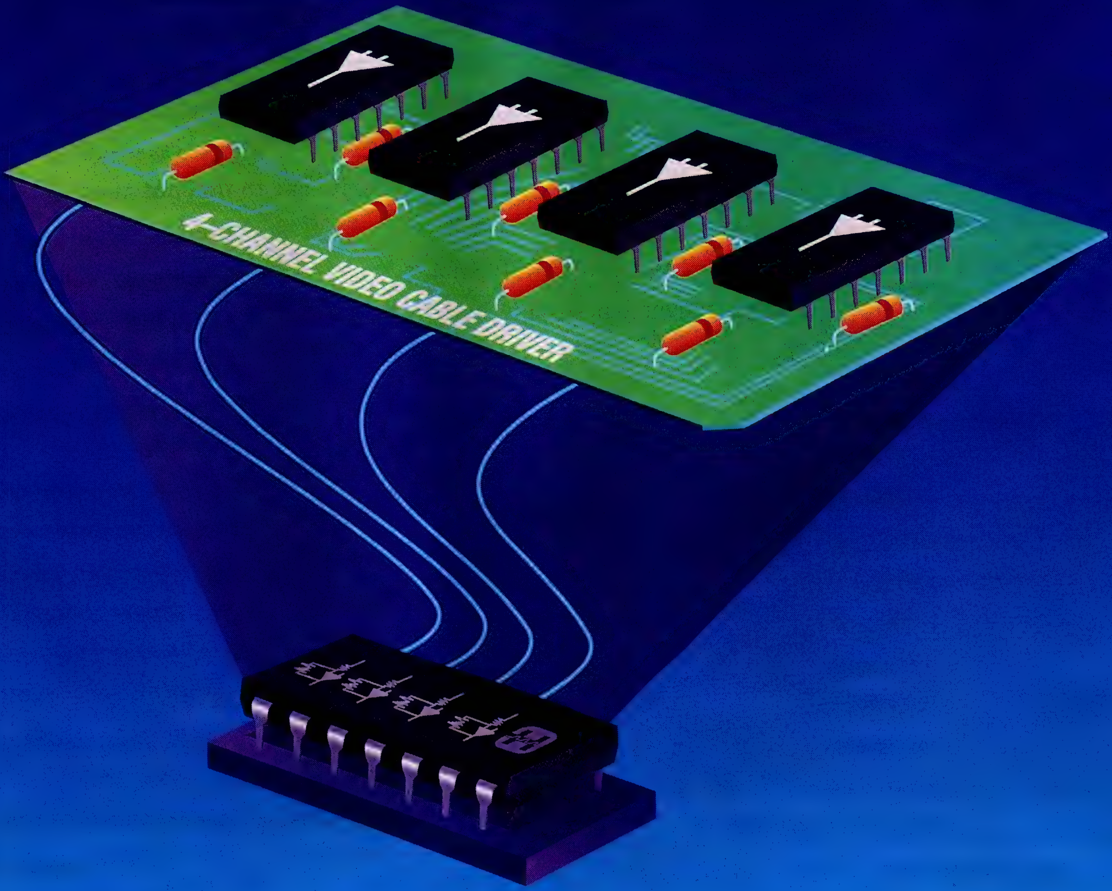


BILL SCHWEBER, TECHNICAL EDITOR

PHOTOGRAPH COURTESY HARRIS SEMICONDUCTOR

Choosing an op amp can be as frustrating as shopping for new wallpaper. You have to peruse multiple data books and parts—much like the dozens of design books at the store, each with hundreds of wallpaper patterns. It's easy to feel overwhelmed and hard to feel confident you've made the *right* choice. Yet, you can be sure that, with a little bit of perseverance, you'll find the *best* selection. To complicate the process, because there are so many parameters that define an op amp, someone will probably challenge your selection by using a different set of priorities.

But don't worry. Even though vendors have introduced dozens of op amps in the past few years, the good news is that many of these devices are far superior to their predecessors. Newer op amps not only reduce the number of frustrating trade-offs among speed, power, cost, accuracy, and size, but also carry more complete specifications.

Best of all, many of these new op amps are application-specific, providing special features unique to an application, along with data sheets that offer relevant specs, characterizations, and how-to-use circuits. You can select a part by its desired function and intended application (for example, driving a 75Ω cable) rather than by looking at an underlying op-amp process technology (FET vs bipolar input or bipolar vs CMOS vs mixed-process fabrication) or a dominant spec, such as output current drive.

By far the largest number of recent op-amp introductions suits low-power, single-supply applications. Note that, although "low power" and "single supply" are technically independent parameters, they are often inseparable needs. A few years ago, op amps were associated with ±15V supplies, which shrank to ±5V then to just +5V; now, nominal +3V supplies (and even lower) are common—with surprisingly little sacrifice in device performance. Wireless applications, such as personal communicators, keyless data entry, RF identification, and handheld test-and-measurement equipment, have driven this supply-rail reduction.

Yet, you should take time to consider operating conditions when applying such low-power, low-voltage devices. They are not as forgiving of system-design shortcomings because they have less input range to accommodate poorly behaved input signals, less head room to defeat unfavorable S/N ratios, and less reserve capacity to overcome output-drive problems.

According to most vendors, common-mode voltage is an area of confusion for designers. The op amp must accommodate your ac signal in addition to a dc signal that may be as large as (or larger than) its supply rail. Although early single-supply devices had common-mode weaknesses, newer devices, such as Texas Instruments' TLV2322 series, can accept an input common-mode range than goes as low as the negative rail and up to within 1V of the positive rail.

The speed-power product has also improved greatly. For example, Elantec's EL2186 and Analog Devices' AD8011 have bandwidths of 250 to 300 MHz (gain of +1) with just a few milliamps of supply current (1 mA for the AD8011, 3 mA for the EL2186) from a ±5V supply. This current consumption represents about a factor-of-100 reduction over the last 10 years.

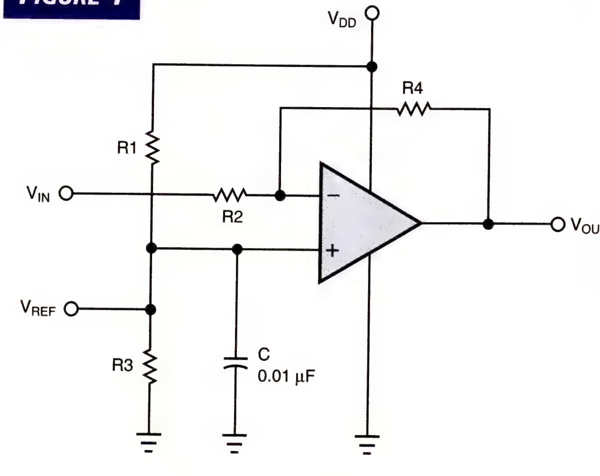
Be wary, however, for there is a trade-off when you focus excessively on low-current operation; even a few extra milliamps from the supply can make a big difference in device performance. Low-current op amps may sacrifice linearity at higher frequencies (despite internal booster circuits) and be "well-behaved" only with resistive loads. Even the capacitance of a scope probe may make the op amp oscillate or peak. Predictable and repeatable performance among units and in production is a factor to consider.

If it ain't got swing

Vendors have developed devices that, like a good race horse, can run fast and close to the rail without stumbling ("close to the rail" is a relative term, of course). Each vendor defines "rail to rail" differently, along with the test conditions. Typically, a rail-to-rail op-amp output can go as close as 100 mV of the supply rail while driving a 1-kΩ load and within 50 mV (or less) of the rail with a lighter load of 10 or 100 kΩ. Note that the supply-span-to-closeness-to-rail ratio is comparable to the one you achieve with a bipolar 15V supply (with its typical swing to within ½V of the negative rail) and within 0.6 to 1.5V of the positive rail.

This rail-to-rail capability doesn't mean that you can stop worrying about the load, though. Not all rail-to-rail devices can maintain performance at full bandwidth. Yet, you need the bandwidth to maintain low distortion and high linearity. When your load is grounded, the op amp has a much easier drive task, because it is pulling the load's high side to ground. When the load is not grounded, the

FIGURE 1



$$V_{REF} = V_{DD}\frac{R3}{R1+R3}$$

$$V_O = (V_{REF} - V_{IN})\frac{R4}{R2} + V_{REF}$$

For bipolar signals, establish a reference level above ground. Although it's easy to do with a simple resistive divider, remember to take op-amp input bias current into account. Lower bias currents also let you use larger value resistors in the divider, thereby reducing power consumption.

op amp must source and sink current, which may require use of internal charge pumps, thus adding to noise and power problems. Some single-supply op amps are not designed both to source and sink current and, when used with split supplies, may have some crossover distortion as the output signal passes through the midsupply value.

Don't forget the op-amp input, either—a rail-to-rail output does not automatically ensure a corresponding input span. Further, many single-supply applications require that you apply a voltage to one input to set an above-ground reference level (**Fig 1**). This reference-setting circuit consumes less power if the op amp has low input bias current, because you can use larger value resistors in a simple voltage divider.

DON'T LOSE SLEEP OVER NOISE

In the past, op-amp noise was a major concern for designers, and it still is in applications such as front ends for extremely low-level signals. However, process improvements have yielded devices with internal noise that is insignificant compared with other system noise sources. Today's typical noise voltages of 2 to 4 $nV/\sqrt{Hz}$ (and noise currents of 2 to 4 $nA/\sqrt{Hz}$) are comparable to the better low-noise devices from just a few years ago. Better control of the fabrication process has also reduced popcorn noise.

This doesn't mean that designers don't worry about noise (**Ref 1**). Even though the ambient digital noise is often far greater than any op-amp noise, it's an emotional, peace-of-mind issue. When you design a low-noise op amp into an application, it's one less thing to worry about, especially since you can't segregate system noise from op-amp noise. Also, although op-amp noise may be lower per root-Hertz, signal bandwidths are now greater in many applications, so the resulting total noise power may still be large. Finally, it's very difficult to compensate for noise-related errors without complex signal-processing algorithms, unlike conventional circuit errors, which you can calibrate out to a large extent.

Stop, think, weigh

You have to begin somewhere when picking an op amp, and, luckily, you have several good strategies from which to choose. One approach is to carefully describe what the input signal looks like, that is, voltage, current, dynamics, ability to source current, etc; what the output should look like (similar criteria); and under what conditions. From this, you can develop a priority list comprising a few most important parameters as well as a few lesser priorities—with desired numbers on each. If there are one or two critical specs, that's fine.

However, if you have three, four, or more critical specs, then you'll have a difficult time finding a part that meets what may be conflicting requirements. The key here is to realize that not every application requires stellar performance; rather, the right op amp is the one with the right combination of specs—none of which is necessarily outstanding on its own.

Fortunately, vendors have made the selection process easier in two ways. Increasingly, manufacturers are classifying op amps in terms of primary application, such as photodiode amplifier, rather than dominant spec, such as low input bias current. Even better, vendors are providing detailed selection trees and guides that begin with the primary application and branch into secondary device characteristics. If you've carefully worked out your needs, these trees will lead you to a half-dozen or so suitable op-amp candidates.

You should understand the specifications of the input signal, its driving circuitry, the output signal, and its expected load (highly reactive loads can cause problems if the op amp is not designed to be well-behaved with these load types). Take time to study the relevant performance-characteristic graphs, which all op-amp vendors provide on data sheets; they are there for good reason. Get some numbers on your noise needs, too (see **box**, "Don't lose sleep over noise").

Equally important, clarify what changes in input or output characteristics, that is, the dynamic nature of the input and output signal and load, your circuitry may experience. For example, will the load change from resistive to capacitive, or can it become a short circuit in some misapplications? Is the load beyond your control? (A simple twisted-pair wire may present anywhere from a few picofarads to a 10,000-pF load.) Or, are you driving a matched impedance load, such as a 75Ω video cable?

Which domain are you in?

Another perspective is to look at op amps from your signal-processing perspective. If you're operating in the time domain, where your circuit must settle to a level when driven by a fast-changing step, your concerns are most likely step response, slew rate, and settling time. Alternatively, if you're in the frequency domain, where your circuit is following a carrier, your needs are defined by bandwidth, distortion, and load driving.

For example, Comlinear provides two "fast" op amps, each characterized quite differently. The CLC402 specs provide settling time, offset, gain range, and differential gain and phase error; the CLC409 specs encompass small signal bandwidth, harmonic distortion, and output current.

Examine data-sheet test conditions. Specifications that look adequate at nominal temperature and supply voltage may not be attainable at operating conditions that deviate from nominal. Fortunately, many vendors are now providing more thorough specifications, including performance at extremes. Typical specs, of course, do not indicate *maximum* and *minimum* performance you'll encounter. DC specs are usually available with typical and maximum (or minimum) qualifications, and ac specs such as settling time and noise are often typical values (not guaranteed by test). This situation reflects practical difficulties the vendor has in testing on a high-speed, mass-production basis; however, with some devices, such as Linear Technology Corp's LT1122, all units are tested for settling time.

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Once you have a clear understanding of what you are trying to accomplish and what performance you need to achieve this, you have two nonexclusive choices: Study the data sheets more carefully or call for help. Vendors know that good customer support is a necessity for op amps, particularly with the bewildering array of op-amp possibilities as well as application subtleties. Therefore, once you've narrowed your choice of vendors and specific models (or families), make those calls to the vendors' applications engineers (the same people who have put all those circuits and application hints on the data sheet). You should also ask for samples. But, don't mislead yourself by thinking you'll have both time and opportunity to evaluate dozens of op amps. Instead, concentrate on the few parts that are promising candidates.

Cost is often the top priority in applications. As with nearly all ICs, the cost of op amps has decreased—including higher-performance devices, too. As usual, you'll look for the least expensive part to meet your needs. But, keep your eye on the big picture. Sometimes, a slightly more expensive part with lower quiescent current decreases system costs by allowing you to use less efficient parts elsewhere, or it provides you with an extra margin of performance certainty and insurance.

LOOKING AHEAD

The driving forces for op-amp improvements continue to be lower power (with single supply), smaller size, and tailored functionality. Video, communications (wired, wireless, and fiber), and PC applications are demanding specific combinations of performance attributes—and at very low prices. You'll also see enhancement in output drive and robustness to handle real-world loads. Although accuracy and precision will improve, they are already sufficient for the majority of applications.

Vendors are now providing op amps targeted at specific applications, such as video, communications, and optoelectronics. This move is nothing new, however; some op amps have always been better suited for certain applications than others (see **box**, "Oldies but (still) goodies"). The difference now is that there are many more such parts, and they're classified by application rather than specs. Fortunately, the industry hasn't started to use acronyms for application-specific or application-optimized op amps!

In addition, vendors have modified packaging and functionality to meet the unique needs of well-defined applications. Video-application requirements, in particular, are driving many newer op-amp designs, and these parts come with comprehensive video-relevant specs, such as differential gain error, differential phase error, and gain flatness to a 0.1-dB drop-off bandwidth (rather than the traditional –3-dB bandwidth point).

Consider the common task of driving a video monitor with the three RGB signals. In this situation, a three-channel IC (rather than a dual or quad one) makes most sense. To minimize layout-routing contortions, parts such as the Maxim MAX463 series have inputs on one side of the package and outputs on the other. This design contrasts with a package having multiple channels used independently, where input and output pins are arranged alternately around the package (**Fig 2**).

The uniqueness of some video signals leads to other application-specific designs as well. To drive A/D converters, the Harris HFA1103 functions as a "sync stripper" by removing the sync signal from the component video sig-

OLDIES BUT (STILL) GOODIES

The outpouring of higher performance and specialized op amps in the last few years means that you should normally consider newest devices first for cost-effective, highest performance results. Yet, despite these new parts, a few older ones are still quite popular (excluding the generic 741 and its immediate variants). Although newer, superior parts are available, some older devices have many successful design-ins and, thus, are inexpensive, exhaustively characterized, appear on your approved-vendor list, and are often second- or multiple-sourced (comparable to the ubiquitous 2N2222 transistor).

Equally important, the older parts' idiosyncracies are well-known to vendor application engineers, which is a major advantage when doing an analog-signal-processing circuit design. Remember that the *best* op amp for your design is the one that has the right, hard-to-define combination of specs, rather than simply excelling in one dimension. Ever-popular op amps (older than six years) include

- the AD847 (from Analog Devices), a 50-MHz op amp with 300-V/μsec slew rate and video specifications
- the LT1007 and LT1037 (from Linear Technology), low-noise (4.5-nV/√Hz to 10-Hz), high-speed (60-MHz) precision op amps for low-level instrumentation signals (with most critical specs guaranteed)
- the LTC1052 (from Linear Technology), a chopper-stabilized op amp for instrumentation with 30-pA input current and extremely low drift of 100 nV/√month
- the LM324 (from Motorola), a moderately low-power device that operates from single or bipolar supplies, with a supply differential range of 3 to 36V
- the LM6361 (from National), a wideband (50-MHz), 300-V/μsec single-supply op amp, which settles to 0.1% in 120 nsec
- the TLC27xx series (from Texas Instruments), featuring low drift (0.1 μV/month), allowing you to select a trade-off in power dissipation vs dynamic specs, from 3.4 mW down to 50 μW
- the TL06x series (Texas Instruments), a low-power (200-μA/amplifier), low-input bias current (30 pA typ) family that also has TL07x low-noise versions (18 nV/√Hz at 1 kHz).

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ZHL-6A	.0025-500	21	+23	+24	350	BNC	199
ZHL-1042J	10-4200	25	+20	+15	330	SMA	495
ZRON-8G	2000-8000	20	+20	+15	310	SMA	495

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TABLE 1—SELECTED OP AMPS (ALL SPECS TYP)

Vendor	Device	Channels	Small-signal bandwidth (MHz)	Slew rate (V/µsec)	Input offset (mV)	No-load supply current (mA/channel)	Supply range (V)	Price (1000)
Analog Devices Inc Circle No. 301	AD813	3	125	500	2	5.5	+3 to ±15	$3.74
	AD8036	1	350	1600	2	17	±3 to ±5	$4.12
	AD8011	1	300	2000	2	1	5 to ±5	$1.95
	OP279	2	5	3	3	3	4.5 to 12	$1.31
Burr-Brown Corp Circle No. 302	OPA129P	1	0.5	0.5	0.15	1.8	±5 to ±15	$2.70
	OPA544T	1 2 (OPA2544T 2A/channel)	1.4	8	5	15	±10 to ±35	$6.00
	OPA642P	1	450	380	1	29	±5	$5.45
	OPA658U	1 2 (OPA2658T) 4 (OPA4658T)	900	1700	4.5	5.75	±5	$1.95
Comlinear Corp Circle No. 303	CLC407	1	110	650	1	3.5	±5	$1.59
	CLC425	1	1700	350	0.1	5 to 15	±5	$3.95
	CLC428	2	160	500	1	11	±2.5 to ±5; 5 to 12	$5.49
	CLC449	1	1200	2500	3	12.6	±5 or +10	$4.20
Elantec Inc Circle No. 304	EL2166C	1	110	1500	2	7.5	±3 to ±15	$2.90
	EL2176C	1 2 (EL2276C)	70	800	2.5	1	±1.5 to ±5	$1.99
	EL2186C	1 2 (EL2286C)	250	1200	2.5	3	±1.5 to ±5	$2.49
	EL4430C	1	80	380	2	13.5	±1.5 to ±15	$3.00
Harris Semiconductor Corp Circle No. 305	HFA1103	1	180	1300	6	11	5	$3.25
	HFA1113	1	850	2400	8	21	5	$5.50
	HFA1114	1	850	2400	8	21	5	$5.50
	HFA1412	4	350	1100	2	6	5	$7.41
Linear Technology Corp Circle No. 306	LT1206	1	50	600	15	5 to 20	±5 to ±15	$3.30
	LT1259	2 3 (LT1260)	130	900	10	5	±5 to ±15	$3.95
	LT1366	2	0.4	0.13	0.15	0.375	1.8 to 36	$3.46
Maxim Integrated Products Circle No. 307	MAX473	1 2 (MAX474) 4 (MAX475)	10	15	0.7	2	3 to 5	$1.45
	MAX492	1 2 (MAX495) 4 (MAX496)	0.5	0.2	0.2	0.15	±1.35 to ±3; 2.7 to 6	$2.25
	MAX472	1	N/A	N/A	0.06	0.1	3 to 36	$2.05
Motorola Semiconductor Corp Circle No. 308	MC33201	1 2 (MC33202) 4 (MC33204)	2.2	1	6	0.9	±0.9 to ±6; 1.8 to 12	$0.76
	MC33102	2	4.6	1.7	0.15	0.75	±2.5 to ±15	$1.20
	MC33304	4	2.2	0.7	3	500	1.8 to 12	$1.60
National Semiconductor Corp Circle No. 309	LM6142	2 4 (LM6144)	17	5 to 50	0.3	0.65	2.7 to 24	$2.10
	LM6361	1	50	300	5	6.8	5 to 30	$1.75
	LMC7101	1	1		4	0.5	2.7 to 15	$0.75
	LMC6462	2	0.05		0.5	0.02	3 to 15	$1.85
Texas Instruments Inc Circle No. 310	TLE2662	2	1.8	3.4	2	0.56	3.5 to 15	$1.95
	TLE2682	2	10	40	0.9	1.5	3.5 to 15	$1.96
	TLE2301	1	8	12	0.3	2.2	±15	$3.64
	TLV2362	2	7	2.5	1	1.4	±1 to ±3	$0.63

Note: N/A=Not applicable.

Applications/attributes
Video, cable driving; disable per channel.
Clamping, driving converters, IF/RF stages.
Video switches, imaging.
For audio; ±80-mA drive, 0.01% THD.
Electrometers.
High-power: 4A output; full protection.
Very low distortion (–90 dB) at 5 MHz.
Video, imaging.
Has disable, for video mux; internal resistors for gains of ±1, +2.
Ultra-low noise for preamps, RF, photodiodes, active filters, ultrasound.
Closely matched low-noise devices; integrators, differential amps, twisted-pair driver, IQ receivers.
Video, RF/IF, driving converters.
Video amp, mux; cable driver.
Video amp, cable driver; HDSL.
Video amp, cable driver; HDSL.
CMV to ±12V, CMRR 70 dB at 4 MHz; line receiver, differential to single-ended conversion.
Sync stripper for video.
Output limiting, programmable gain.
Cable driver with summing node.
+2, ±1 internal gain resistors.
250-mA output; adjustable quiescent current.
Video drivers; individual shutdowns.
Rail-to-rail; stable for capacitive loads up to 1000 pF.
Portable instrumentation.
Drives large capacitive or 1-kΩ load.
High-side current sensing; 35-mΩ internal resistor; current up to 3A.
Goes to 50 mV of rail.
0.045 mA in sleep mode; 4-µsec wake-up.
Rail-to-rail; 110-µA sleep mode.
Wide supply range, rail-to-rail input and output; loads to 300 pF.
Unlimited capacitive load.
SOT23-5 package; rail-to-rail input and output; mobile communications and personal digital assistants.
Rail-to-rail, very low power and offset.
Output to 0.000V, sinks 25 mA; low-level signal conditioning; also includes switched capacitor dc/dc converter as a negative supply source.
Higher speed version of TLE2662.
1A output; three-state output; thermal shutdown.
Audio, general purpose, low voltage.

nal (**Fig 3**). The device accomplishes this task by having an open emitter npn transistor in its output stage, thus preventing the output from going low during the sync pulse. As a result, only active video information (not sync) passes to subsequent stages; this move allows your design to maximize use of the A/D converter's dynamic range, and it avoids inadvertent saturation of the converter input.

If your application involves selecting one of several video sources, you'll look at op amps with output disable. With these ICs, you can build a multiplexer function without a separate multiplexer IC by paralleling or ORing the outputs of several channels. This approach not only reduces parts count, but also frees you from worry about any additional offset from the multiplexer or additional channel-to-channel differences within the multiplexer IC.

Other video applications are directly related to the CRT interface. If you're driving XGA high-resolution monitors (1024×768 pixels), you need both amplification plus range control for each channel's drive to let you adjust the monitor's color to match its associated color printer. Devices such as National's LM1208 are designed for these needs, with 130 MHz of bandwidth and 6 dB of drive control range.

Op amps with a twist

Some op amps transparently add features that require little or no deliberate action by system software. For example, although it's possible for system software to put an op amp into power-saving shutdown mode, Motorola's MC33304 quad op amp makes the shutdown decision entirely by itself. When a signal that causes the amp's output to source or sink over 210 µA is applied, the device switches to awake mode (consuming 500 µA/amplifier); when output current drops below 70 µA, the amplifier automatically switches to sleep mode and consumes 110 µA/amplifier.

Despite load uncertainties, you can also choose devices designed to ease your task rather than concentrating primarily on input and signal processing needs. With Linear Technology's LT1224 series, the device is guaranteed to be stable, regardless of capacitive-load size. Of course, the amplifier's dynamic performance changes with differing loads, and you have to study

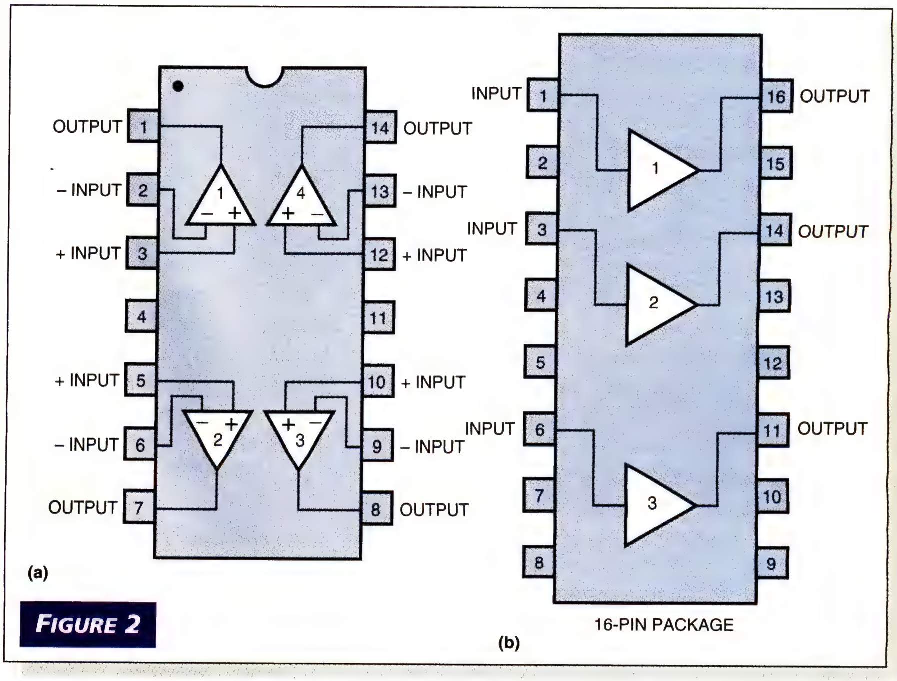


FIGURE 2

For applications such as RGB video drivers, the pinout of a quad op amp (a) complicates pc-board layout, which contrasts with the pinout of a video-specific triple amplifier (b).

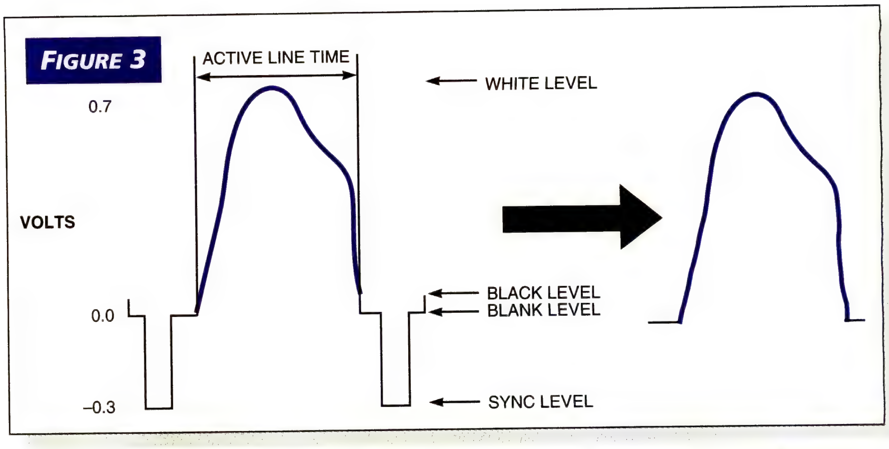
data-sheet curves carefully.

In video or communications applications, your input signal is often not "well-behaved" and may overrange or suffer sudden noise bursts. This out-of-range condition overloads the sensitive front ends of subsequent stages, which then take milliseconds to return from saturation (during which time signal-handling is lost). One solution is to limit the buffer amp output by clamping it to a low-impedance source through a series resistor and diode from the active line to each supply rail. This approach not only adds at least four discrete components, but also consumes considerable power. Even worse, there's a conflict: The buffer output driver needs to be low-impedance to drive the converter input capacitance, and the clamp must have low impedance to yield good clamping action. A low impedance driving a low impedance is a recipe for component failure.

A better solution is to use a clamping amplifier (**Fig 4**), such as Analog Devices' AD8036, Harris' HFA1135, or Comlinear's CLC501/502, which provide you with linear response within the normal input range along with "graceful" limiting at the extremes. This response is combined with fast recovery from clamp mode—typically, a few nanoseconds.

For optoelectronic applications, you can reduce component count, performance uncertainty, and cost by using an IC that has the photodiode and its required buffer amplifier in a single package. Burr-Brown's OPT211, for example, includes a photodiode and transimpedance op amp as a monolithic device in a clear eight-pin package, which also acts as an optical filter (**Fig 5**). The single-chip solution eliminates common problems of leakage current on the circuit board, noise pickup in critical paths, and gain peaking result-

FIGURE 3



A video sync stripper removes the timing signal, leaving the active part of the composite signal for further processing and digitizing.

MODELING IS NOT AS GLAMOROUS AS IT SOUNDS

Virtually every op-amp vendor provides Spice models, which are a very useful approximation of device performance. A good model attempts to resolve two contradictory impulses: It should use a minimum number of internal elements (especially nonlinear ones) to ease computing yet look like an accurate representation of the op amp as a "black box" (see **Ref 2**).

You should use these models as a necessary (but not entirely sufficient) step in the design process. Models cannot capture a device's every sensitivity to supply variations or temperature and load changes. Dynamics such as slew rate and overshoot are especially difficult to model. For current-feedback devices, where bandwidth is set by a feedback resistor at a given gain, it is very difficult for vendors to model performance at every closed-loop gain value.

Most available Spice models use typical rather than worst-case specs. Equally important, even a perfect model (if available) would not capture what's just as critical in high-performance analog design: your physical circuit that surrounds the part. Even a few picofarads of circuit-board capacitance affect peaking, for example, and conductive residues on the circuit provide a leakage path between IC pins. No op-amp model captures what your ground topology looks like.

All models are not created equal. The first op-amp Spice models, based on work by Boyle in 1974, used two poles, did not characterize supply or output current well, and referenced internal signals to ground. Although some models still use this approach, most vendors now have more sophisticated models, such as seven-pole configurations, which provide good trade-offs among complexity, convergence, and accuracy. In addition, vendors now pay extra attention to modeling the input and output stages of the op amp—which, after all, are the op amp's interface to your circuit.

Does this mean you shouldn't use models? Absolutely not! Use them for first-level assessments of your circuit, to about ±20% accuracy. At the same time, recognize that the model itself neither is perfect nor includes the subtleties of your design. Check with the vendor to understand which modeled specs are typical, which are worst-case, which are at room-temperature, and other similar limitations and simplifications.

Most vendors offer evaluation boards and suggested circuit-board layout drawings. Don't hesitate to use them. First, an evaluation board shows you what the part can do in an (assumed) optimal design. Second, the layout can serve as a reference design for your work, so you won't waste time discovering mistakes the application engineers have already made—and fixed. According to several vendors, the first question their engineers ask when a designer calls with a problem such as oscillation in high-frequency current-feedback circuits is, "Did you use the evaluation board design?"

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ing from stray capacitance—attributes that models cannot easily accommodate (see **box**, "Modeling is not as glamorous as it sounds").

"Trimming" is a concept (and a chore) that has been associated with op amps since their earliest days. The most frequently performed trim lets you reduce or eliminate input-voltage offset, which shows up as a static output error. Trim's visible cost to you is one component (a trimming potentiometer), a larger op-amp package (those null pins), and some board space. Less tangible costs include additional production and test time, opportunity for misadjustment, and potential unreliability.

CURRENT VS VOLTAGE FEEDBACK

You must also consider op amps that use current feedback topology instead of the more familiar voltage feedback. Although there are many views about the virtues (and vices) of each, look closely at the benefits of each topology in your application.

Voltage feedback is what you probably learned in school; it's got those nice equations and looks simple to set up and probe. In current feedback, the error signal that feeds back to the input stage is, as the name states, a current; the input buffer's low output impedance allows large currents to flow through the negative input. This current is the slewing current, and slew rate is a function of the feedback resistor and change in output voltage. Therefore, the current-feedback amplifier has nearly constant output transition times, regardless of step size.

In performance, current feedback generally offers higher slew rate and lower power consumption than voltage feedback, and voltage feedback offers you flexibility in selecting a feedback resistor, two high-impedance inputs, and higher precision. With a current-feedback op amp, you set the bandwidth via an external resistor, which also allows you to make some design trade-offs among gain, bandwidth, and stability. You can use the same part in several places for quantity cost savings, using only as much bandwidth as needed to reduce noise energy.

In general, current feedback is used only at higher frequencies, for applications such as professional video and high-performance instrumentation. Even at higher frequencies, some designers prefer to stay with voltage feedback, because they believe it's easier to use. Current feedback is less common in lower end consumer applications because it requires more design expertise.

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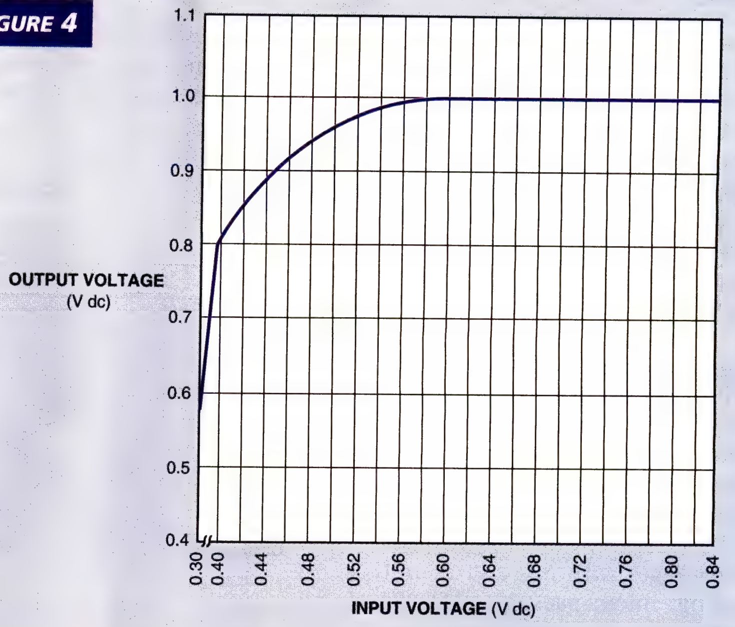
Uniformly, op-amp vendors say that users don't want to do trims, and that they no longer have to in most cases. First, as a result of design and process improvements, offsets have gotten much smaller. Precision op amps now feature offsets below 100 μV. (Even better, the offset temperature coefficients—which cannot be trimmed easily—are also lower.) Also, trims are unnecessary in ac-coupled applications where the dc level is not relevant, such as in communications.

Even for dc applications, you can compensate for situations where a precision part isn't good enough by using software-driven calibration (in most cases). You'll probably need to do this calibration, anyway, to take care of various nontrimmable system errors.

Your ability to calibrate (and thus eliminate) errors, changes the traditional error-budget approach to analog-circuit design. Rather than work out elaborate spreadsheets to calculate the effect of various error sources (and thus avoid discussions over whether you

FIGURE 4



Clamping amplifiers provide a smooth transition into limiting mode at both extremes of the input-signal excursion, thus preventing saturation and overload (and time lost comes out of saturation) in subsequent stages; this feature is especially useful where the dynamics of the input are not well-behaved.

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should add typical or worst-case errors or perform root-sum-square calculations), you'll do better by stepping back and questioning which types of system calibration are most effective. Question the implications of a sufficiently accurate "known" signal as part of calibration—and what errors this move will correct; also, determine which types of errors it won't correct.

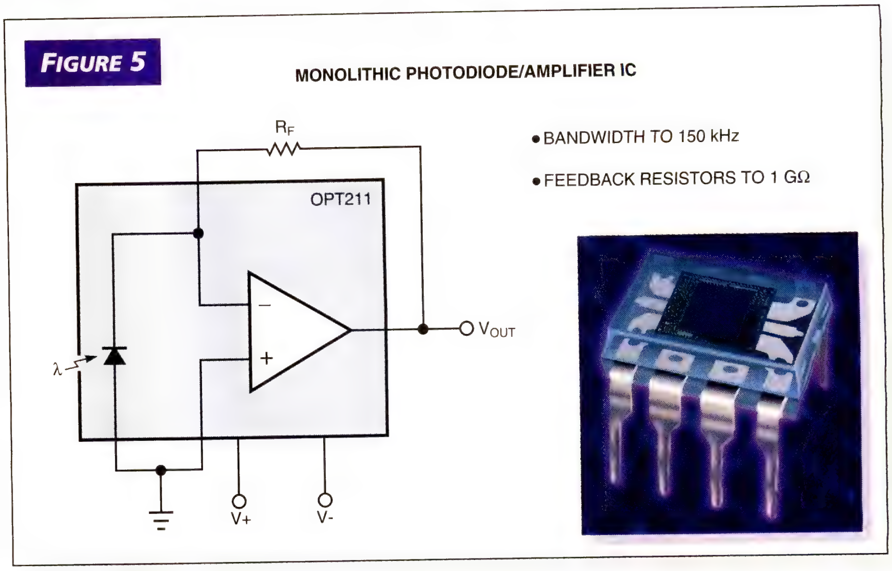
Packaging and pins to fit

As if the plethora of op amps weren't enough, you also have to select from available packages. The ubiquitous eight-pin DIP for a single op amp has been supplemented (and partially supplanted) by small-outline surface-mount packages with 50- and 25-mil pin spacing, micro packages, TSSOPs (thin shrink small-outline packages), SOT-23 five-pin packages (3.05× 3×1.44 mm thick, which is approximately half the size of an SOIC), and more (**Fig 6**). Of course, the part with specs you need may not be available in the package style you want.

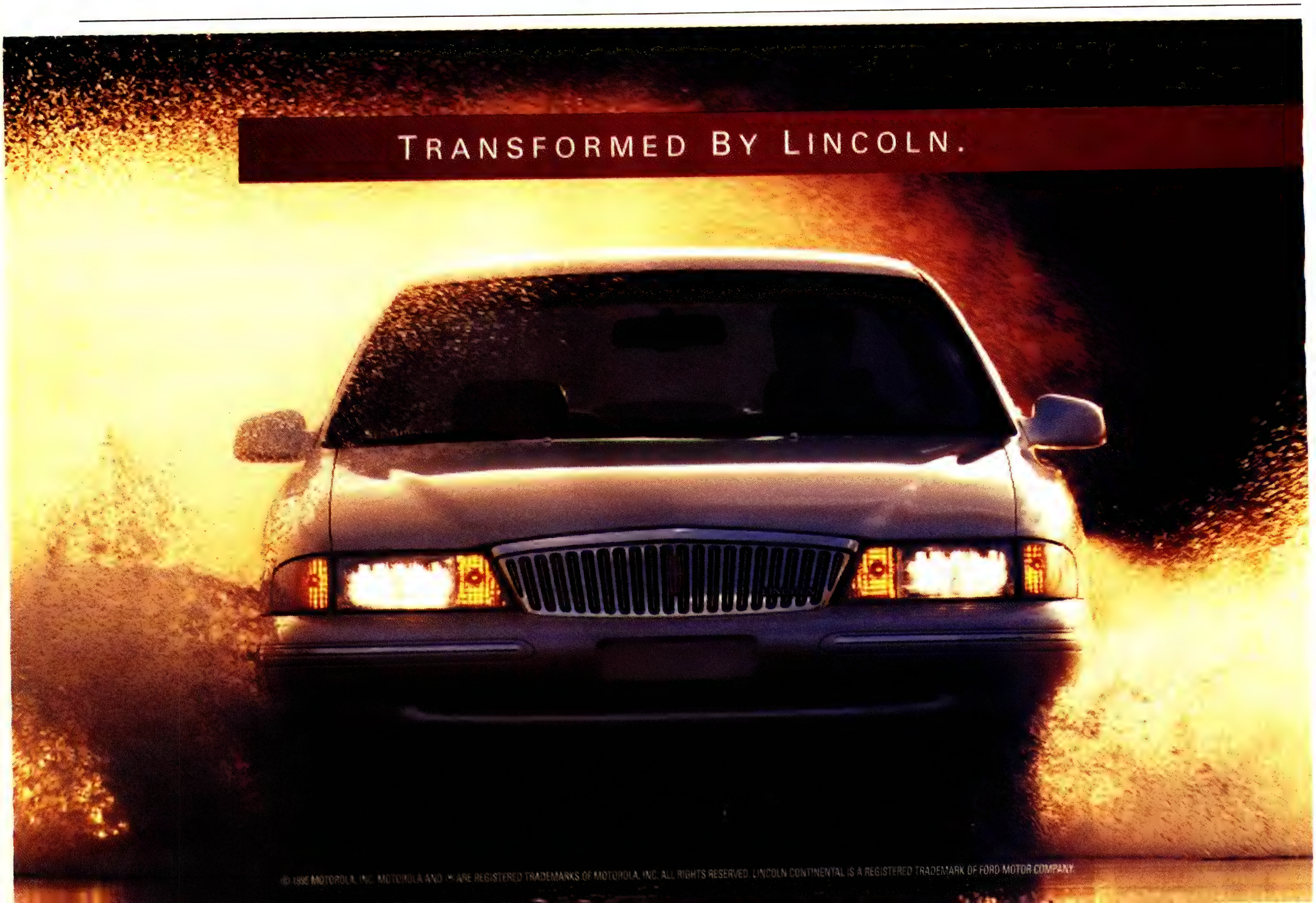
The packaging issue involves not just package type but pinouts. In the past, you could safely assume that virtually all op amps were at least available in that least-common-denominator eight-

FIGURE 5

MONOLITHIC PHOTODIODE/AMPLIFIER IC



Integrating a photodiode and its preamp into a single device, as in this Burr-Brown device, requires both appropriate electronic design and a clear package that actually functions as an optical bandpass filter.



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pin DIP, so you could substitute and upgrade far along in your design—or even in production. Now, though, as op amps fragment for different applications, that's no longer true: A part intended for handheld phones has a package that's quite different from a part for driving cables in PCs.

Some parts are available only in dual or quad configurations because their single-channel versions would find few applications that are cost-effective. (In contrast, highest speed op amps, with bandwidths above several hundred megahertz, are often available in singles only, due to internal crosstalk problems.) Multichannel parts offer advantages besides saving board space and money. They often have quiescent currents only slightly greater than a single-channel device, but with better offset, temperature tracking of drift, matching, and other specs.

However, pinouts in multichannel configurations are much less standardized than the basic single-channel unit,

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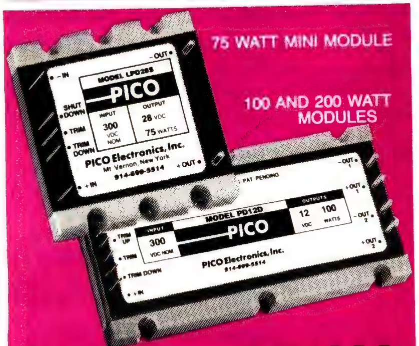

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so substitutes are harder to find. You can even find high-performance eight-channel op-amp ICs, but check carefully before you design them in—they may be too much of a good thing in layout routing.

The old rule for op amps went something like this: You'd always need a second source—or at least an alternate source with comparable specs. Again, times have changed. For several reasons, designers no longer insist on backup sources for parts. The average product life cycle is much shorter than the lifetime of a good op amp. In addition, qualifying another source (you can't assume that other source will perform identically) is a task that many designers don't have time or expertise to do fully. Finally, if you're doing leading-edge design, you'll choose parts that give you the competitive edge (even if they are proprietary) and for which there may be nothing comparable in performance, cost, and functionality. Where the part will make the difference, carefully consider vendor competence and credibility. EDN

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1. Rich, Allan, "Noise Calculations in Op Amp Circuits," LTC Design Note 15, September 1988.
2. Christensen, John, "Simulating Analog Systems with Macromodels," *Sensors*, March 1995, pg 24 to 26.

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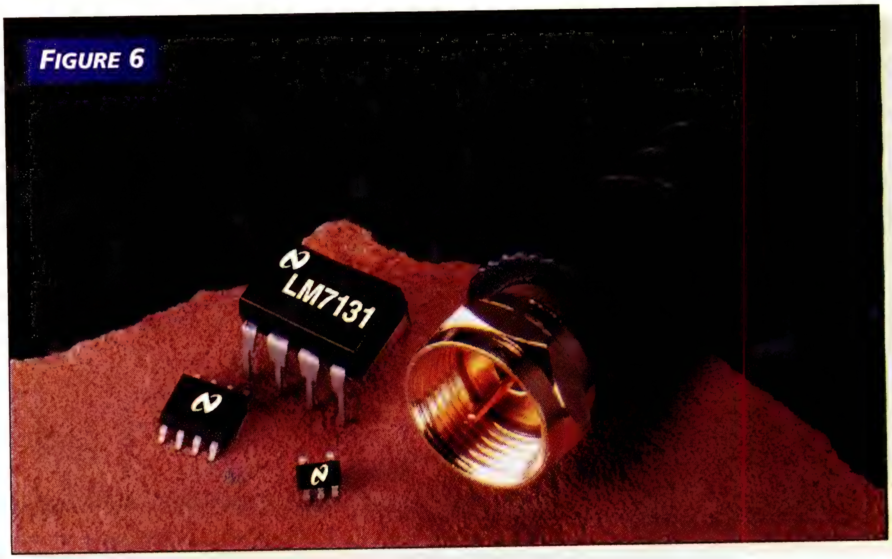
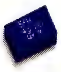
FIGURE 6



Package proliferation: The familiar eight-pin DIP for through-hole use has been been joined by the smaller, surface-mount eight-pin SOIC package. Many op amps for portable equipment are available in the even-smaller five-pin SOT23-5. (Photo courtesy National Semiconductor Corp)



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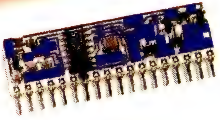

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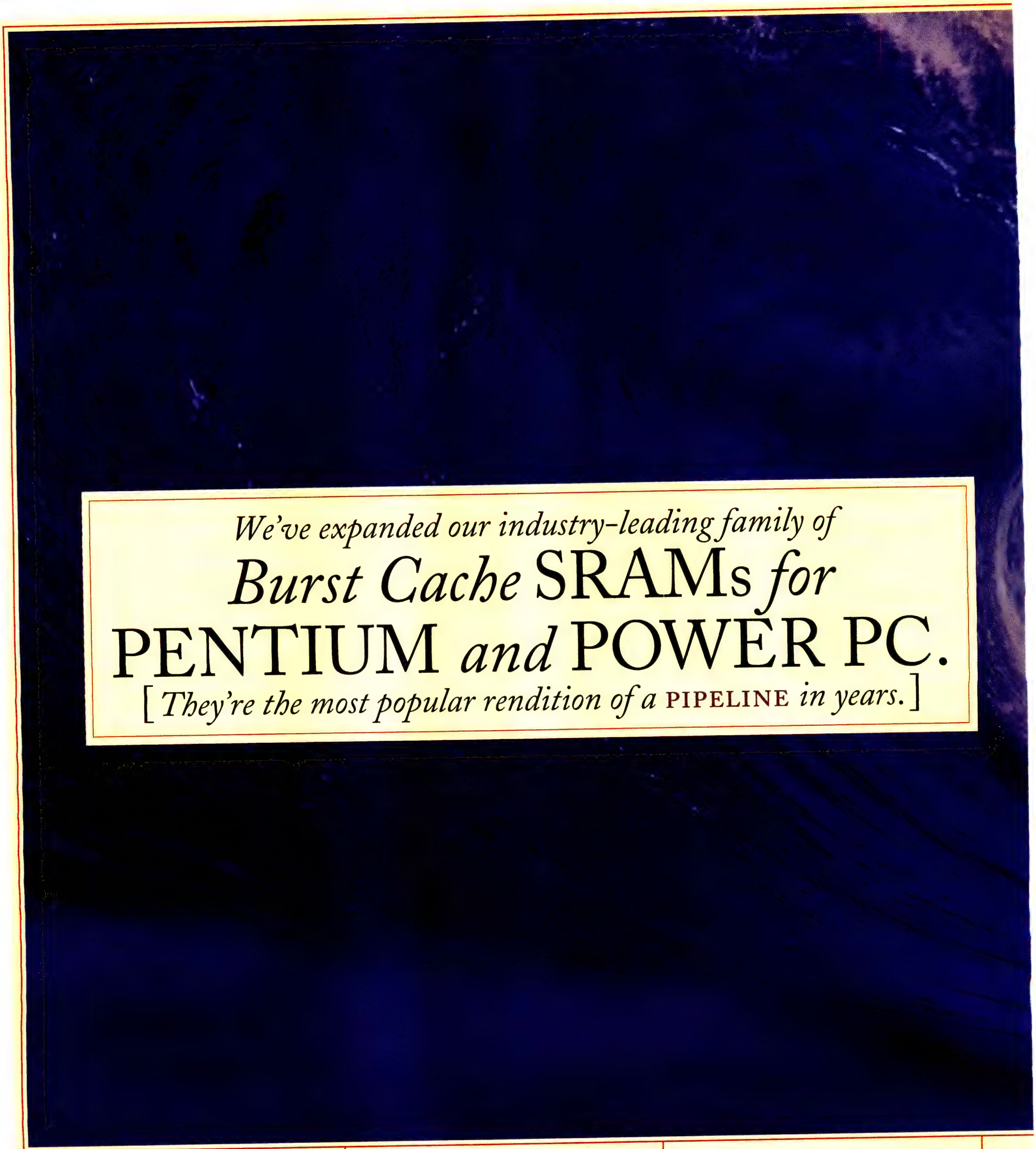

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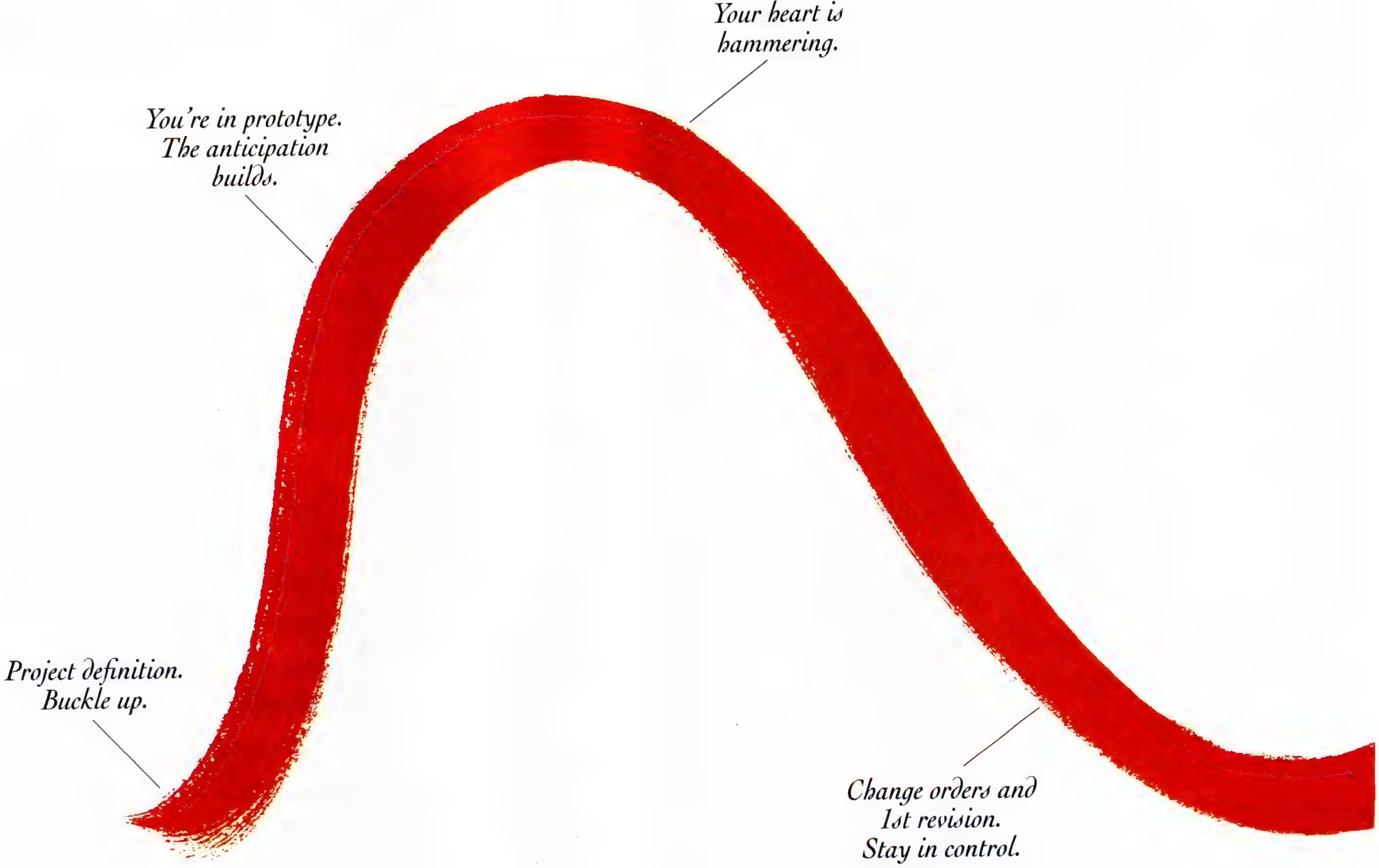

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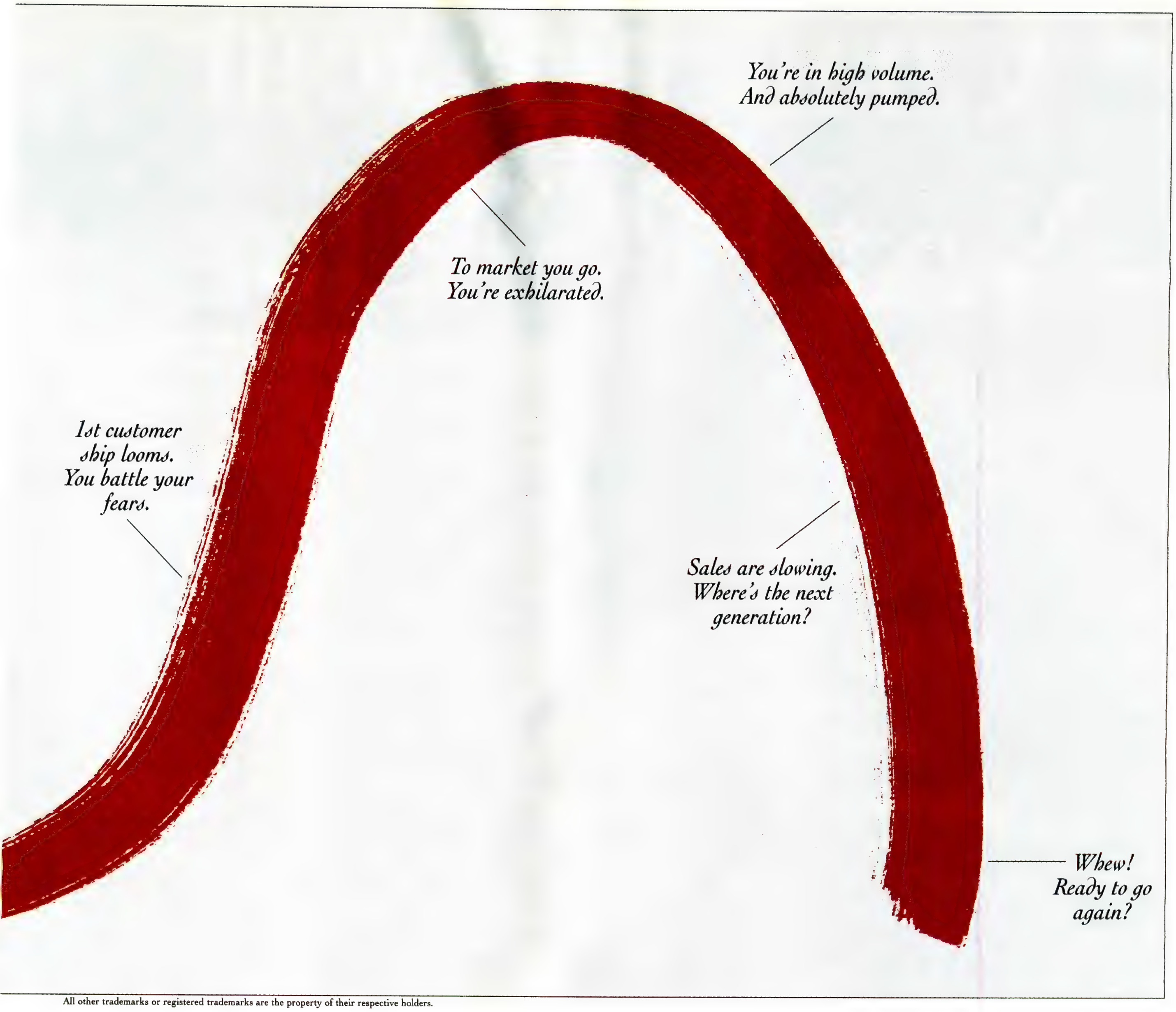

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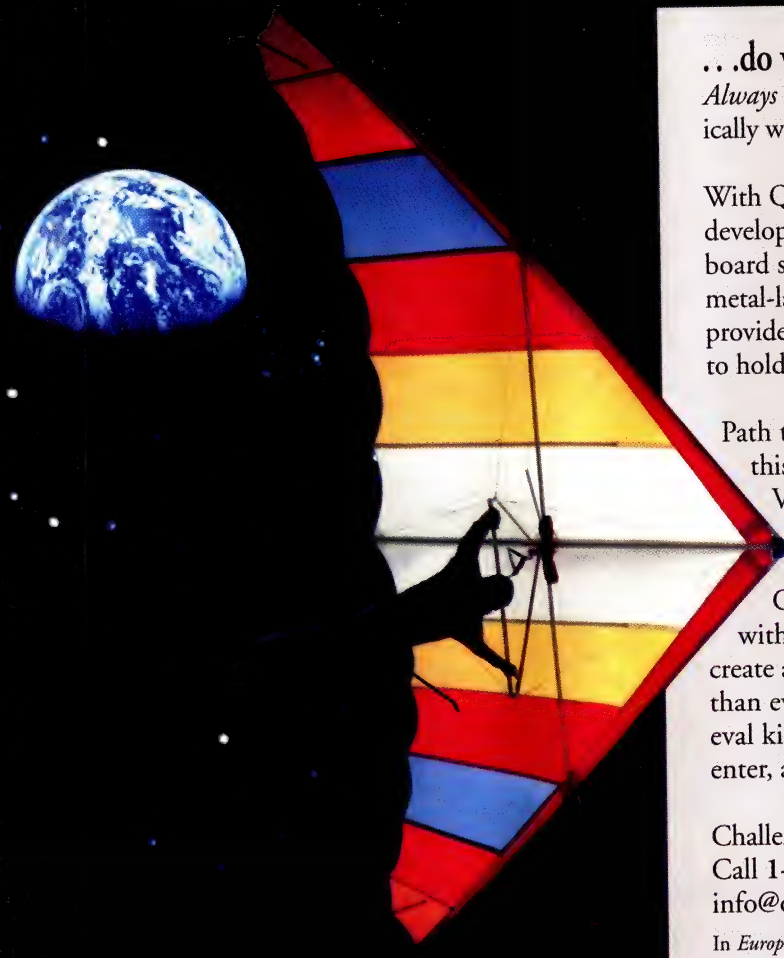

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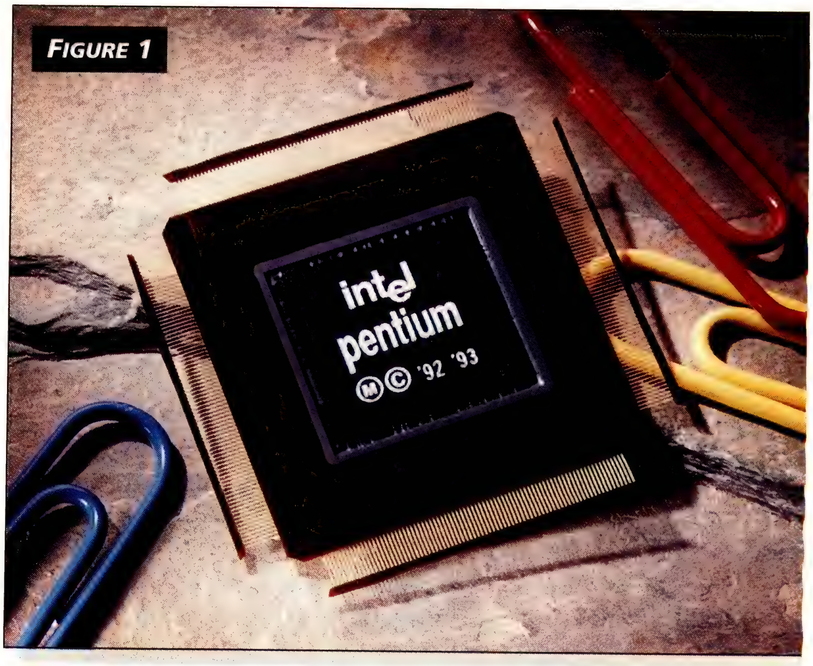
DAN STRASSBERG, SENIOR TECHNICAL EDITOR

So many pins; so little room! Unremitting demands to develop more compact and capable products have brought about ICs of increasing speed and complexity with more I/O lines. Meanwhile, the space for mounting those ICs is shrinking, causing conventional peripheral-leaded, surface-mount IC packages to hit a wall. New packaging technology offers solutions, and ball-grid arrays (BGAs) are just the beginning. The new technology will have a major effect on the way you design and debug products. In your next product, individual chips might not have any packages at all.

As the number of pins in a conventional surface-mount package increases, providing enough room for reliable solder connections requires more area—not less. As the package grows, so do the capacitance (C) of signal leads to their neighbors, the lead inductance (L), and the lead resistance (R). Higher values of C, L, and R degrade signal fidelity at the clock rates of today's high-speed circuits.

This situation has caused some in the industry to predict the demise of packaged ICs. These pundits claim that, to eliminate package problems, you must eliminate packages. Thanks to effective oxide and nitride passivation, uncased IC dice can withstand more abuse than you might think. But, uncased chips are still frail and easily damaged. Testing individual uncased devices presents greater problems for IC manufacturers than does testing of packaged ICs. Moreover, assembling products that use uncased ICs involves technology that differs radically from that with which most assembled-product manufacturers are familiar.

FIGURE 1



This tape-carrier-package version of Intel's Pentium μPs is popular with manufacturers of notebook PCs. The package, which occupies a 29-mm-sq space on a pc board, is just 0.7 mm high. The package's volume and weight are about one-fortieth those of the Pentium PGA. Nevertheless, Intel sells both versions for the same price.

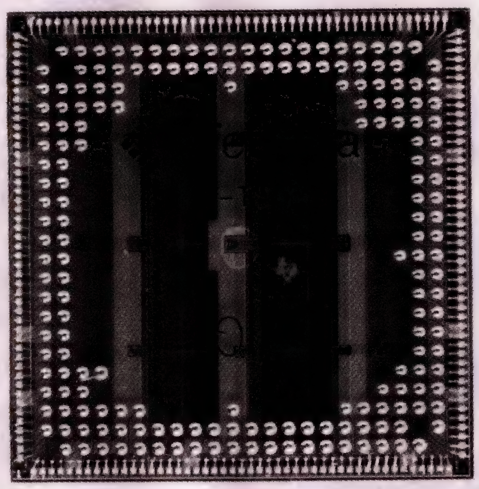
Right now, intense interest focuses on BGAs. By moving the solder joints from around the package periphery to the space between the package and the pc board on which it mounts, these surface-mount packages allow much more room for connections while holding the package size constant or even shrinking it a bit. A BGA with 300 leads on 0.06-in. centers (a current industry-standard spacing) can be smaller than a peripheral-leaded package with the same number of leads on 0.015-in. centers. Whereas the solder bumps, or balls, beneath the mounted BGA are less accessible than the leads on the conventional package, both package types present formidable probing problems.

Assembled-product manufacturers are enthusiastic about BGAs. The packages, though not free of problems, work with the automated pick-and-place machines that are so common on surface-mount assembly lines. Preserving this investment is important to assembly managers, who require packaging technologies to work with existing processes and equipment unless compatible packages simply don't meet product cost or performance objectives.

Although you can't visually inspect the solder joints beneath a BGA, the generous space between joints reduces the likelihood of solder bridges. In addition, during reflow, surface tension of the relatively large amount of molten solder beneath a BGA tends to align slightly misaligned devices with the conductive patterns on the pc board. Moreover, recently developed test schemes, such as IEEE-1149.1 boundary scan, reduce the need for visual inspection and probing.

Vendors of test accessories are working on the BGA probing problem. BGA sockets already exist, mainly for burn-in. Sockets that permit probe access are a simple extension to the burn-in sockets. However, in many cases, such sockets don't fit on prototype boards, let alone on production versions. Moreover, the sockets add inductance and capacitance that can degrade the performance of high-speed circuits. Test compa-

FIGURE 2



In this view of Tessera's μBGA, the flex-circuit faces you, and the slightly larger test die is beneath it. At the flex-circuit's perimeter are almost-microscopic fingers that attach it to bonding pads around the die's periphery. Close to the flex-circuit's perimeter are nearly 200 tiny, gold-plated solder bumps in several rows.

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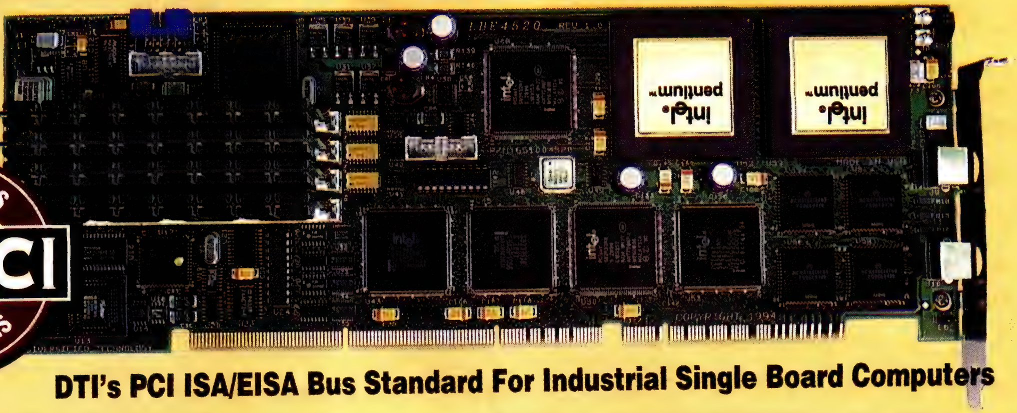

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LOOKING AHEAD

Over the next year, the industry will move to smaller packages that are compatible with existing IC and pc-board assembly processes and equipment. Such packages include ball-grid arrays (BGAs) of many types and higher density peripheral-leaded packages, such as Archistrat's VSPA. These packages will coexist with conventional peripheral-leaded surface-mount packages. You'll see many boards that mix the more advanced packages with the more familiar types.

Although several companies are comfortable with using uncased dice in assembled products, these companies will remain in the minority. Most manufacturers would rather use chip-scale packages (CSPs), such as Tessera's μBGA, for products requiring the ultimate in miniaturization. But the key word is "ultimate." Unless size or electrical characteristics require the use of CSPs, assembled-product manufacturers will stick with larger packages, such as BGAs.

IC manufacturers are among the most aggressive users of advanced packaging technology. Witness Hitachi's use of the μBGA in a larger BGA, Toshiba's use of tape bonding in packages that look conventional from the outside, and Intel's recent announcement that the initial version of its P6 μP will contain two chips in a single package that some call a multichip module. Using advanced packaging is a practical, intelligent strategy for IC manufacturers, because the processes closely resemble those used in IC manufacturing. By using processes similar to those in which they are already expert, IC manufacturers add value where it makes sense. At the same time, they enable their customers to focus on processes familiar to pc-board assemblers.

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nies are working on better ways to probe BGAs, and products should emerge late this year. Though unwilling to reveal details yet, the companies admit that the products will entail compromises and predict that achieving high signal fidelity will be costly.

Despite the excitement they are generating, BGAs are neither the only nor the most advanced new IC packages. To make informed decisions among packaging alternatives, you need to know about the major package types, their strengths, and their weaknesses. To understand about IC packages, you should begin by understanding how IC manufacturers and assemblers of products that use uncased dice (multichip modules (MCMs), for example) make connections to ICs. In nearly all respects, the connection techniques are the same

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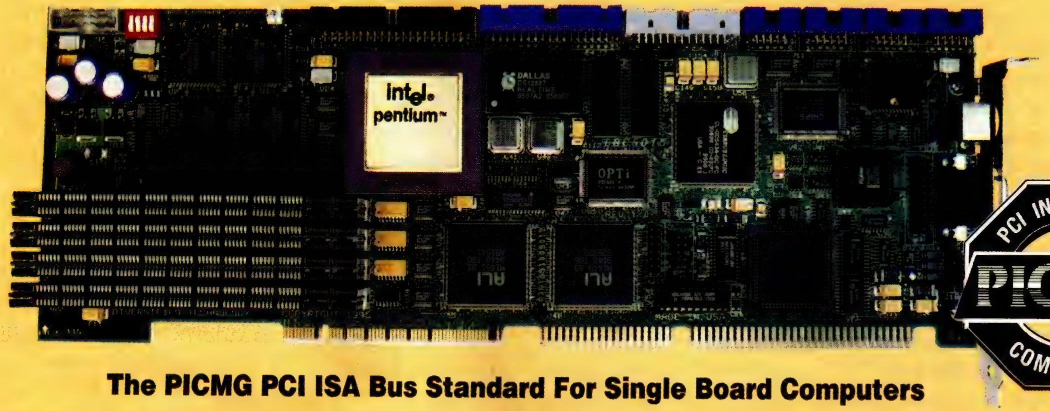

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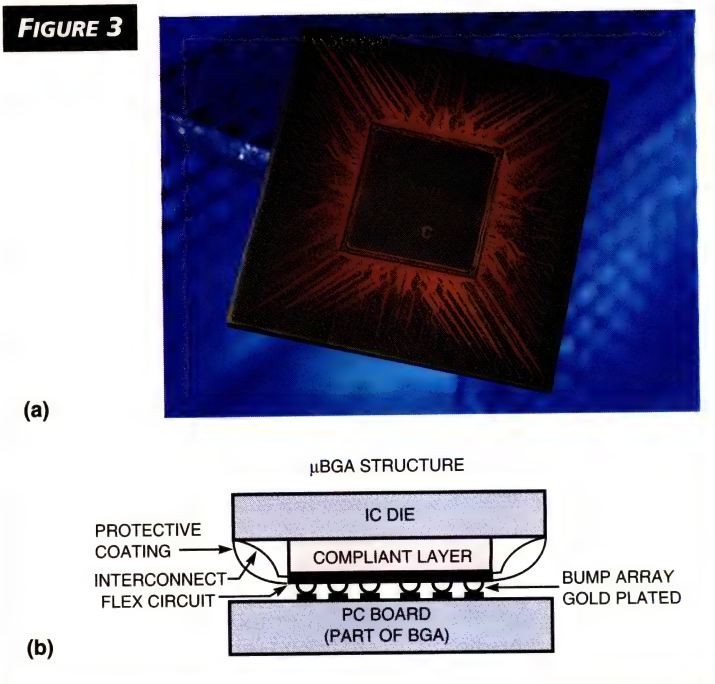
whether a package contains one die or a dozen dice.

IC manufacturers handle smaller parts than those pc-board assemblers must handle. However, both groups face similar problems. Wire bonding—for decades, the most popular method of connecting to IC chips—seems near the end of its life. Other lead-attachment methods, such as tape, ball, and bump bonding, appear better able to achieve the connection densities today's high pin-count ICs require. Ball and bump bonding solder face-down dice (flip chips) directly to a substrate. Wire bonding works only with face-up dice; tape bonding works with either face-up or face-down dice, although the dice face upward during bonding.

A few years ago, many people believed that new packages unique to tape bonding would become industry mainstays. Although several such packages have emerged, they have found limited acceptance. Tape bonding lives on, though. Vendors, such as Toshiba, are using it to replace wire bonding on high-pin-count parts. You often can't tell from the outside that a package contains a tape-bonded part. Tape bonding allows very high connection density: Currently, the minimum center-to-center spacing is 62.5 µm. This spacing allows over 600 connections around the periphery of a square die that has a 1-cm edge dimension.

FIGURE 3



Hitachi builds this 672-pin BGA package (a) around Tessera's µBGA technology. The pc board in the cross-section view (b) is part of the BGA package. This pc board makes a transition from the very fine-pitch solder bumps on the flex circuit adjacent to the die to larger bumps on the BGA's bottom surface.

Regardless of the lead-attachment technique, most IC dice have bonding pads near their edges. Locating the pads near the die edge is essential for wire and tape bonding. With ball and bump bonding, the pads can be anywhere on the chip surface. Regardless of the pad location, ball and bump bonding (like BGA technology for packaged devices), saves space and lead length by moving the device-to-substrate connections from outside the device perimeter to under the device.

But, flip-chip bonding is a mixed blessing. One disadvantage is that a die change, such as a shrink, that does not affect an IC's performance can force the designer to redesign the substrate. If a product uses packaged ICs, such die changes have no effect on substrate designs. Another disadvantage of flip-chip bonding relates to differences in the thermal coefficients of expansion (TCEs) of silicon and of substrate materials, particularly organic materials.

Unpackaged dice—especially those connected face-down to a substrate—transfer most of their dissipated heat to the substrate. Organic substrates' TCEs are much greater than those of IC chips. Because it expands more than the chips do, an organic substrate places a large mechanical stress on the solder bumps and the dice as it heats. Repeated power cycling causes the solder bumps and ICs to fatigue and eventually fail. How soon failure occurs depends on the power dissipation and the number of bonds. TCE-mismatch problems are less severe with face-up-mounted chips, because manufacturers can use permanently compliant material to fasten the dice to the substrates.

Ceramic substrates improve flip-chip reliability because their TCEs are closer to those of silicon; with silicon substrates, the TCE mismatch is negligible. Ceramic and silicon substrates are more costly and more fragile than organic substrates, however. In addition, when you bond a low-TCE ceramic package face-down to a pc board, power dissipation within the package expands the board and places high stress on the solder connections between the package and the board. The problem is somewhat less severe than the one that exists with flip-chip-bonded bare dice on organic substrates because the ceramic packages and solder bonds are more massive and, hence, more rugged than those used with bare dice.

IBM and other companies have developed proprietary compliant materials to fill the space between flip chips and organic substrates. Such materials also work between low-TCE ball and bump-bonded IC packages and pc boards. The companies claim these underfill materials increase by at least an order of magnitude the number of power on/off cycles the ICs and solder bonds withstand. Thus, by making flip-chip bonding to low-cost substrates more practical, the underfill materials make MCMs more practical. Still, using flip chips with underfill has drawbacks. Without underfill, you can remove defective ICs from a substrate. With underfill, the entire module must go to the scrap heap if even a single IC fails.

Because each decision about MCM processes invokes a list of pluses and minuses, debates about MCM-construction details abound. Similar debates affect BGAs. In their excitement over the technology, IC manufacturers have attempt-

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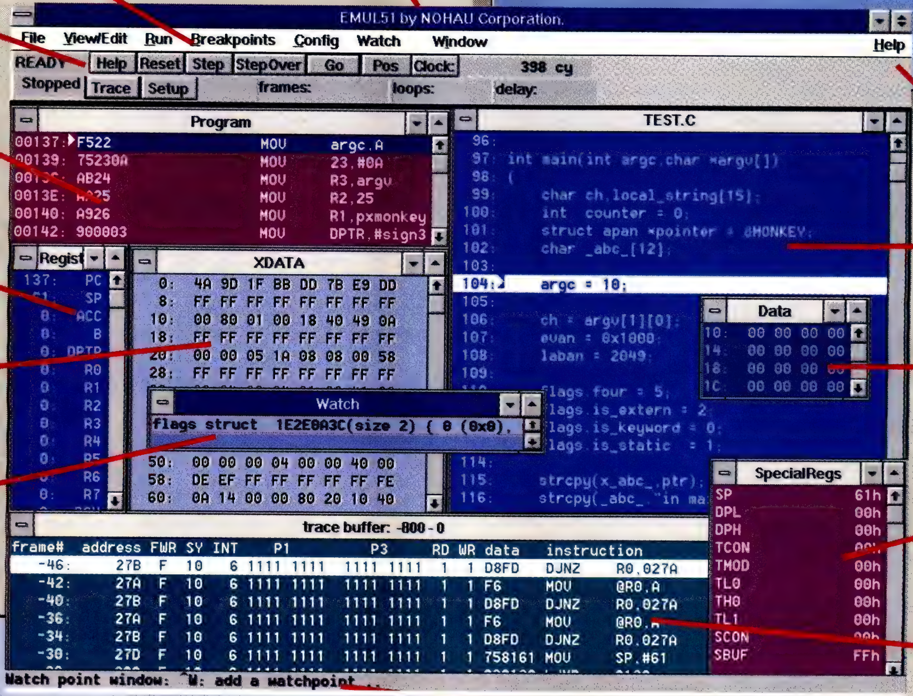

```
398 cy
```

```
00137:▸F522      MOV   argc,A
00139: 75230A    MOV   23,#0A
0013C: AB24      MOV   R3,argv
0013E: AA25      MOV   R2,25
00140: A926      MOV   R1,pxmonkey
00142: 900003    MOV   DPTR,#sign3
```

```
137:   PC
 61:   SP
  0:  ACC
  0:    B
  0: DPTR
  0:   R0
  0:   R1
  0:   R2
  0:   R3
  0:   R4
  0:   R5
  0:   R6
  0:   R7
```

```
 0:  4A 9D 1F BB DD 7B E9 DD
 8:  FF FF FF FF FF FF FF FF
10:  00 80 01 00 18 40 49 0A
18:  FF FF FF FF FF FF FF FF
20:  00 00 05 1A 08 08 00 58
28:  FF FF FF FF FF FF FF FF
50:  00 00 00 04 00 00 40 00
58:  DE EF FF FF FF FF FF FE
60:  0A 14 00 00 80 20 10 40
```

```
flags struct  1E2E0A3C(size 2) { 0 (0x0),
```

```
 96:
 97: int main(int argc,char *argv[])
 98: {
 99:     char ch,local_string[15];
100:     int  counter = 0;
101:     struct apan *pointer = &MONKEY;
102:     char _abc_[12];
103:
104:▸    argc = 10;
105:
106:     ch = argv[1][0];
107:     evan = 0x1000;
108:     laban = 2049;
109:
         flags.four = 5;
         flags.is_extern = 2;
         flags.is_keyword = 0;
         flags.is_static  = 1;
114:
115:     strcpy(x_abc_,ptr);
116:     strcpy(_abc_,"in ma
```

```
10:  00 00 00 00
14:  00 00 00 00
18:  00 00 00 00
1C:  00 00 00 00
```

```
SP     61h
DPL    00h
DPH    00h
TCON   00h
TMOD   00h
TL0    00h
TH0    00h
TL1    00h
SCON   00h
SBUF   FFh
```

```
frame#  address FWR SY INT    P1         P3       RD WR data   instruction
  -46:     27B   F  10   6 1111 1111  1111 1111  1  1 D8FD   DJNZ    R0,027A
  -42:     27A   F  10   6 1111 1111  1111 1111  1  1 F6     MOV     @R0,A
  -40:     27B   F  10   6 1111 1111  1111 1111  1  1 D8FD   DJNZ    R0,027A
  -36:     27A   F  10   6 1111 1111  1111 1111  1  1 F6     MOV     @R0,A
  -34:     27B   F  10   6 1111 1111  1111 1111  1  1 D8FD   DJNZ    R0,027A
  -30:     27D   F  10   6 1111 1111  1111 1111  1  1 758161 MOV     SP,#61
```

```
Watch point window:  ^W: add a watchpoint ..
```

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ed to register more than 100 BGA-package outlines. Such enthusiasm can work to BGAs' detriment. To be successful, a package needs the support of an infrastructure. (Examples of infrastructure elements are sockets and simulation models for both packages and sockets.) With so many packages, vendors of infrastructure elements don't know where to apply their limited resources.

The many BGA outlines reflect the many ways to build BGAs. With one popular technique (albeit not one that accommodates the highest pin-count ICs), the IC manufacturer uses a compliant adhesive to attach the die, face up, to an organic substrate. The substrate, which forms the package bottom, is a tiny multilayer pc board. Wire bonds provide the connections between the die and the substrate. The IC manufacturer can cap the package with an organic top or can first coat the die with compliant material and then create a "glob-top" BGA by capping the package with rigid epoxy. For the IC manufacturer, the beauty of this approach is that it uses

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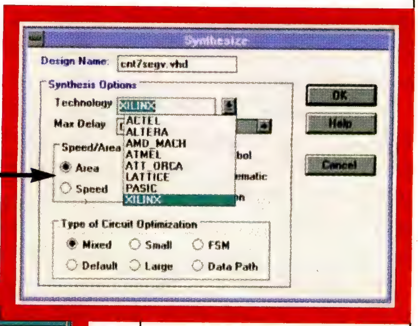

Design Name: cnt7segv.vhd

Synthesis Options
Technology: XILINX
ACTEL
ALTERA
AMD_MACH
ATMEL
ATT_ORCA
LATTICE
PASIC
XILINX

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Type of Circuit Optimization: ● Mixed ○ Small ○ FSM ○ Default ○ Large ○ Data Path

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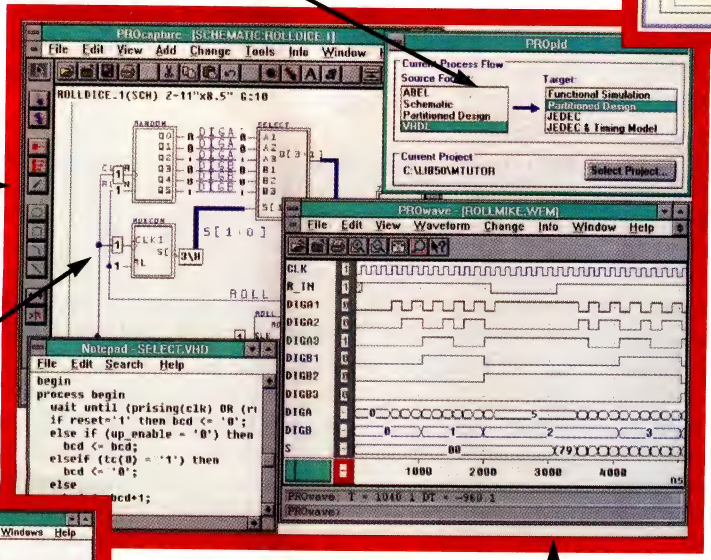

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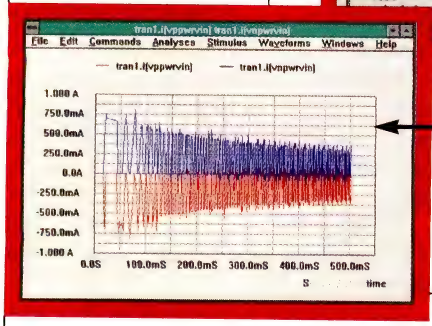
Target: Functional Simulation, Partitioned Design, JEDEC, JEDEC & Timing Model

Current Project: C:\LIB50\MTUTOR

PROwave: T = 1040.1 DT = -960.1

```
begin
process begin
  wait until (prising(clk) OR (r
  if reset='1' then bcd <= '0';
  else if (up_enable = '0') then
    bcd <= bcd;
  elseif (tc(0) = '1') then
    bcd <= '0';
  else
        bcd+1;
```



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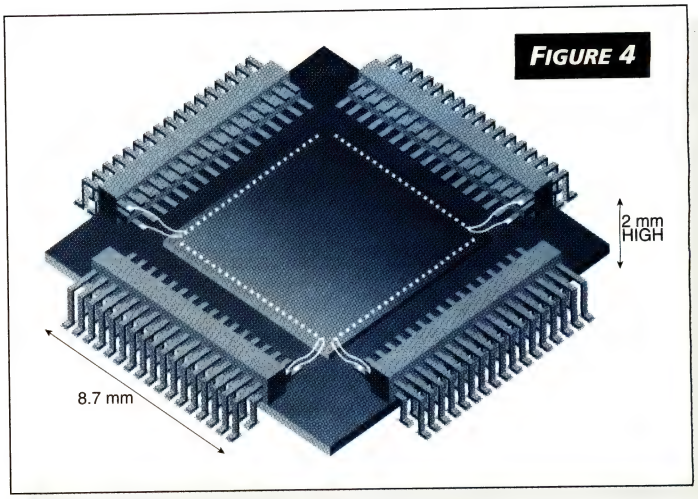
FIGURE 4

By using multiple rows of pins, Archistrat's VSPA significantly reduces the area a packaged IC requires on a pc board, yet spacing between solder joints is much greater than with other high-density peripheral-leaded packages, and package assembly can use conventional processes. This two-tier 144-pin VSPA is 64% smaller than a 128-pin QFP. Three-tier VSPAs are also in the works.

existing processes and equipment, such as die and wire bonders.

A dramatic and widely publicized shortcoming of plastic BGAs (PBGAs) is the so-called popcorn effect. During solder reflow, the expansion of entrapped moisture can pop open the packages with small, popcorn-like explosions. IC vendors and board assemblers claim to have solved the popcorn effect long ago. The solutions involve coating packages to keep moisture out and slowly heating the devices before soldering. Nevertheless, memories of such dramatic problems last a long time, and, at companies contemplating the use of PBGAs, popcorn-effect stories are bound to cause some managers to hesitate before using the packages.

Differences among companies underlie the divergent opinions on packages and connection techniques. For example, IBM has a long and successful history of using uncased chips in its own assembled products. A key reason for this success is that the company does something few others do: It makes many of the chips its products use.

Because most assembled-product manufacturers are wary of working with uncased dice, IBM sees a large demand for ICs in small, economical IC packages. Therefore, the company this year began selling PBGA packages to IC manufacturers. The IC companies mount chips inside the packages and resell them to companies that assemble pc boards. Prices for the IBM PBGAs begin at $0.0167/pin for complete packages in large quantities.

Last year, Intel became the first company to announce a line of known-good uncased dice that sell for the same prices and meet the same specs as their encased counterparts. Intel markets the uncased devices under the name SmartDie. Yet, last year, Intel also began selling a tape-carrier package (TCP) version (**Fig 1**) of its Pentium μPs to manufacturers of notebook PCs. A mounted Pentium TCP is 0.7 mm high by 29 mm square—roughly one-fortieth the volume and weight of the PGA version. A 75-MHz Pentium sells for the same price in a TCP or in a ceramic PGA. During the first quarter of this year, that price was $301 (1000). Intel does not currently sell the Pentium in unpackaged form.

TCP Pentium μPs go on pc boards—usually fairly sizable ones. For cost reasons and because of the industry's long history of successfully using such boards, nearly all pc boards are made of organic materials, such as FR-4 and G-10. Packaged ICs better withstand stresses caused by TCE differences between silicon chips and popular board materials. This ruggedness has encouraged the use of packaged chips and discouraged the use of unpackaged dice on boards. SmartDie chips go mainly into MCMs. Most MCMs still use relatively costly ceramic or silicon substrates, primarily because MCMs must match the TCEs of the substrate and the dice.

Testing uncased chips

How to test uncased chips after they have been separated from one another has stymied the industry for years. Now, reusable packages are coming to the rescue. IC manufacturers use these rather expensive packages during test and burn-in. Because hundreds of chips can share the cost of one reusable package, the per-unit package cost approximates that of more conventional permanent packages.

Thanks to reusable packages, MCM manufacturers can be confident that good chips are going into their modules. More precisely, manufacturers that know how to avoid damage to uncased chips during handling can be confident. Knowledge that chips are good is particularly important when modules won't tolerate IC replacement. Even the ability to get known-good dice for the same price as packaged parts, however, doesn't stop the debate about whether you can build MCMs at costs equivalent to building circuits using packaged dice.

Chip-size or chip-scale packages (CSPs) aim to end this controversy by enabling manufacturers to shrink the size of assembled products without forcing a transition to the use of uncased chips. Proponents of such packages are trying to get the industry to accept this definition of a CSP: A CSP occupies no more than 20% more area than the die itself, not counting any area used by leads immediately outside the package perimeter. Peripheral leads on high-pin-count IC packages can easily consume several times the pc-board area that the package body occupies. The bonding wires that connect a face-up bare die to a package or substrate can likewise occupy several times the die area.

Shrinking an IC package so that *it* occupies scarcely more area than the die itself requires significant departures from conventional methods. Package developer Tessera has made such departures in its μBGA (**Fig 2**). Not only does the result occupy little more area than the die, but also little more *volume*. To make a μBGA using Tessera's technology, an IC manufacturer places a tiny, multilayer, flexible printed circuit atop the IC die. A thin layer of compliant material often lies between the flexible circuit and the die. Radiating from the circuit, which is slightly smaller than the die, are minuscule fingers made from one of the flex circuit's inner layers.

As in tape bonding, the IC manufacturer uses thermal

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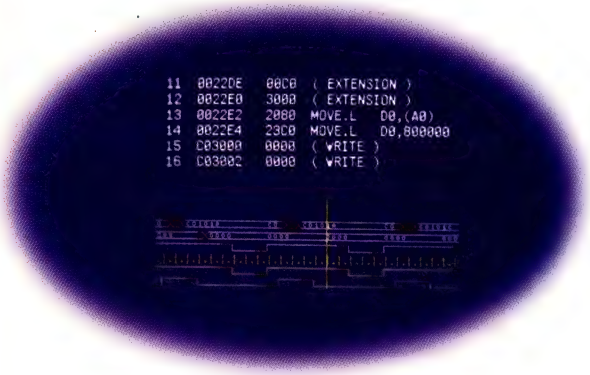

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11  0022DE   00C0  ( EXTENSION )
12  0022E0   3000  ( EXTENSION )
13  0022E2   2080  MOVE.L    D0,(A0)
14  0022E4   23C0  MOVE.L    D0,800000
15  C03000   0000  ( WRITE )
16  C03002   0000  ( WRITE )
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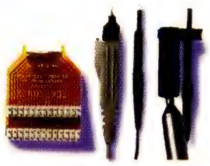

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TABLE 1—ELECTRICAL AND THERMAL COMPARISON: 672-PIN μBGA VS 600-PIN PGA*

	600-pin PGA	672-pin μBGA
Internal inductance		
Power and ground leads	3 nH	1 nH
Signal leads	17 nH	5.5 nH
Internal capacitance		
Signal leads	9 pF	0.4 pF
Internal resistance		
Power and ground leads	200 mΩ	100 mΩ
Signal leads	1000 mΩ	360 mΩ
Thermal resistance	2.5 to 3 °C/W	2 to 2.5 °C/W

*Courtesy Hitachi America Ltd, Semiconductor and IC Division

compression to bond the fingers to pads around the die's periphery. The minimum possible spacing between the pads should approximate that in tape bonding—62.5 μm. On the surface of the flexible circuit, facing away from the die, is an array of solder bumps connected to the fingers. The assembled-product manufacturer reflows these bumps to connect the μBGA to a pc board. Thus, the flex circuit, which was atop the die during package assembly is beneath it during board assembly.

In the μBGA, the flexible circuit's fingers accommodate the differing TCEs of the die and the pc board. When the chip is cold, the fingers are slightly flexed. As the chip heats up, the flex circuit and the pc board beneath it expand more than the die does, further flexing the fingers. The polyimide flex circuit, which covers most of the face of the die, provides the die's main protection. The back of the die can be exposed or covered. Exposing the back of the die allows the best possible thermal contact with a heat sink. The die's most vulnerable area is its perimeter. The IC vendor can encapsulate just this area—first in a compliant material (to preserve the fingers' flexibility) and then in a hard material.

One of Tessera's licensees is Hitachi, which has released the first commercial implementations of the μBGA. One of those implementations is a 672-pin BGA that measures 37.5 mm on an edge (**Fig 3**). Hitachi uses the package to house very high-performance ASICs. **Table 1** compares the package's characteristics with those of a PGA. The package, which is one-third less expensive than a ceramic PGA, is larger than chip size to permit 0.05-in. center-to-center spacing (an emerging industry standard) between the solder bumps in the grid on the underside.

Don't get too close!

How closely μBGA allows you to space hidden solder bumps without causing soldering problems will strongly influence the device's acceptance and that of other true chip-size, bump-bonded packages. Consider Intel's Pentium die. The current version is just under 0.5-in. sq and has about 300 pins. If all connections were beneath the die in a square grid, their centers would have to be less than 0.028 in. apart. Although this spacing is almost twice that of the peripheral leads on the TCP, the number of connections per square inch is about four times current standard practice for hidden solder joints. A die shrink could more than double the density.

Another small IC package is Archistrat's very small peripheral array (VSPA) (**Fig 4**). Connections between the package and the chip use conventional wire bonding, a plus for IC manufacturers because wire bonding is still their favorite method for connecting to chips. The VSPA's leads are around its periphery, allowing assembled-product manufacturers to visually inspect solder joints. Unlike more conventional peripheral-leaded surface-mount-technology packages, however, a multiple-row lead arrangement minimizes the space occupied by the package and its connections to the board. The lead arrangement also permits greater spacing between leads than is possible in packages whose leads are in a single row.

The multiple rows of leads do present probing problems, though. Probing the outer rows is not especially difficult, and you should be able to position individual probes on leads in inner rows. However, simultaneously contacting all of the package leads appears no easier than making simultaneous contact with all of a BGA's leads. Nevertheless, of the new smaller packages, VSPA seems to require the fewest concessions from IC- and assembled-product manufacturers. And the payoff from VSPA is dramatic: A mounted 320-pin VSPA uses only one-fourth of the board area of a 304-pin QFP, despite Archistrat's estimate that the VSPA will cost at least 10% less.

The speed with which the industry moves to wide use of packages smaller than BGAs and VSPAs depends on the intensity of demands for products that offer higher performance, smaller size, and lighter weight. Until a payoff is clear, assembly operations will shun technology that requires process changes. Meanwhile, IC manufacturers will use the new technology internally.

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Software quality: not an oxymoron

The economics of cost overruns and maintenance and the demands of ISO-9000 for European trade are forcing the software and embedded-systems industries to take a critical look at quality. Unfortunately, no quick answers are in sight.

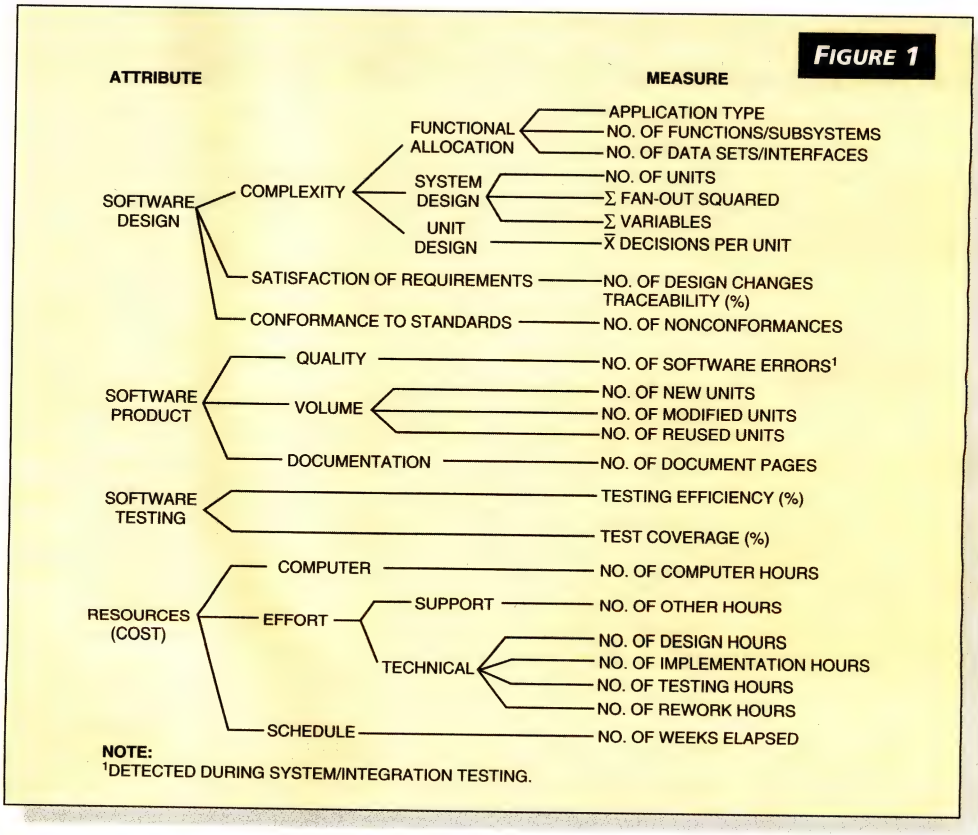
RICHARD A QUINNELL, TECHNICAL EDITOR

Software design has long been more of an art than a technology. As an art, software-design quality depends heavily on the designer's talent, skill, and inspiration. However, today's system needs cannot afford to depend on artistic talents. Turning software design from an art into a technology may require your company to revamp its entire software-development process.

As software's reputation among end users indicates, there has always been concern about software's quality. Many people consider the term "software quality" to be an oxymoron. Software has even earned its own variation of Murphy's Law, called Weinberg's Second Law: *If builders made buildings the way programmers create software, the first woodpecker would destroy civilization.* A more serious indicator of public concern is the attention that software quality has received in the popular media (**Ref 1**).

As software becomes an increasing part of system operation, the electronics industry is also focusing on software quality. Software quality has an increasing economic impact on developers. As software-development projects become larger, the likelihood of cost overruns increases. For example, surveys from software-project-management-consulting-company Software Productivity Research (SPR) show that a project

FIGURE 1



NOTE:
[1]DETECTED DURING SYSTEM/INTEGRATION TESTING.

Measuring your software development can help improve quality by indicating where problems arise. To be effective, such measurements should have a broad-enough spectrum to follow the entire process.

involving 100,000 lines of C code typically takes twice the planned effort. Maintenance costs on poor software can run from two to 10 times the initial development cost.

Many companies incorporate some form of software-quality control. If your company sells to Europe, for example, the organization needs ISO-9000 certification, including certification of its software-development practices (**Ref 2**). Although the ISO-9000 does not require specific methods, the standard necessitates that your company document its methods. That step may be impossible for more than 75% of US companies because they have no method.

Ad hoc methods dominate

According to SPR surveys, from 75 to 85% of software companies use ad hoc or random approaches to software development. These companies fall into the initial, or Level 1, category of the Software Engineering Institute's Capability Maturity Model (CMM) (see **box**, "Measuring your software development's maturity"). Another 10% of companies achieved repeatable, or Level 2, results. Only a handful of companies actually managed well-defined software development.

The low ranking of most companies doesn't mean that they are trying to produce poor-quality software. Many manufacturers have development standards, such as module-size limits and the use of structured programming, that they hope can engender quality. Companies use tools such as diagrammatic programming to ensure more accurate designs (**Ref 3**). But, tools and programming standards have not proven to be guarantors of quality (**Ref 4**).

LOOKING AHEAD

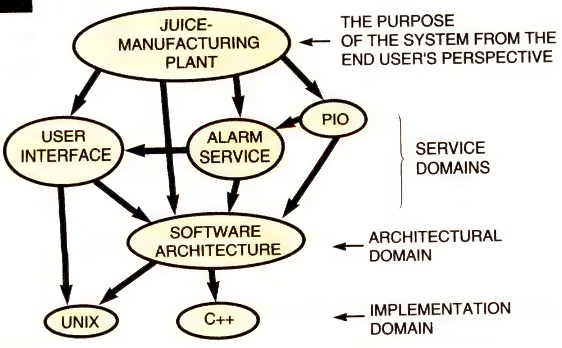
The emergence of commercial tools for advanced methods such as Shlaer-Mellor heralds a shift in the software industry to more formal, repeatable design methods. Formal methods are not new; code reviews have been around for 20 years. However, the need for such methods is new. Software size and complexity have grown to the point that ad hoc methods are no longer sufficient.

No one method can lead to higher quality software. Despite marketing claims from computer-aided software-engineering vendors, tools and programming styles by themselves aren't effective. Attaining high-quality software requires a systematic approach covering everything from definition of requirements to final test. In addition, this approach must have the backing of corporate commitment, time, and money. Tools and methods alone aren't the answer: You also need the desire.

THE SHLAER-MELLOR METHOD

The Shlaer-Mellor method for software development is an example of an advanced development process that is gaining commercial support. You begin by breaking the project into domains that a team can independently analyze as a single unit (**Fig A**). If a domain is too large for analysis, you break it into independent subsystems.

FIGURE A



Object-oriented analysis breaks your project into domains, starting with the application. You then analyze the domains in order. Arrows between domains show where one domain imposes constraints on another.

Next, you analyze the domains, starting with the application domain, which describes what the system is supposed to accomplish. You analyze domains by first creating an information model describing the system's elements and the relationships among them (**Fig B**). You build state models that describe the behavior of each system element from the information model. Then, you create an action-flow diagram that describes the processing required in each state model. At no time does the analysis specify how the system performs its processing. The analysis only details the data, steps, and timing that the application needs.

Application-domain analysis results in a model that completely describes the application's behavior. You can simulate the application using this model and check that your analysis is correct. By evaluating the simulation's outcome against the expected results, you can verify that the application will perform properly.

Analysis of the application domain places requirements and constraints on the next domain for analysis, the service domain. The service domain describes all the functions or services that the software must provide to execute the processing models. Analysis proceeds as in the application domain and yields a set of requirements on a lower level service domain. Ultimately, the analysis process yields

Most Level 1 software-development efforts concentrate on generating, debugging, and maintaining code. Errors made in the overall design or design specifications don't show until system-integration tests begin. Then, the design team makes patches to the initial code to correct the problems rather than recoding. The equivalent in hardware engineering would be a company's using its prototype pc board for final production rather than laying out a new board from a corrected schematic. The production product ends up with many cut traces and blue-wire jumpers.

The industry's emphasis on debugging and maintaining code has resulted in great efficiency at detecting and removing coding errors. The industry can boast a 95% code-defect-removal rate (**Ref 5**). However, if there is a mistake in the overall design, the debugged code may be correctly executing the wrong function. **Table 1** shows the origins of software errors in an average program. Coding errors comprise only one-third of all software errors that enter final test and only 12% of the errors in production software. The remaining errors come from other steps in the development process, such as defining initial specifications.

Upgrade the process

This diversity of error sources implies that, to be effective, any attempt to upgrade software quality must involve the entire development process. The development process should use methods that prevent, as well as remove, defects. One such method is the formal peer (not management) review of specifications, designs, and code. The review process typically provides about a 60% defect removal. In addition, all designers at the review can learn from the errors found and avoid making similar mistakes.

Another method to include in a software-quality upgrade is measurement and tracking of software-quality attributes throughout the design process. As **Fig 1** shows, such attributes can include quality metrics such as design complexity, test coverage, and measures of the team's design efficiency. You cannot hope to recognize where the problems or improvements occur without using a few of these measurements. For the use of metrics to be effective, you must understand your development process. Otherwise, you won't know where to find the problems that the metrics indicate.

Large projects, new methods

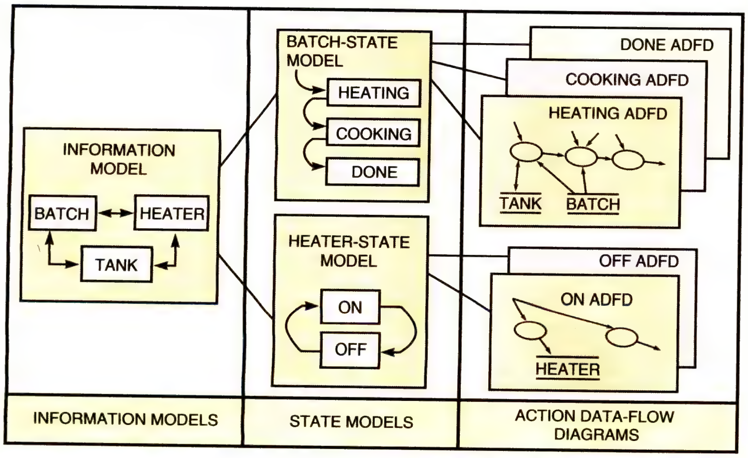
Although peer reviews and the use of metrics effectively improve software quality, they may not be enough if your design requirements change during the project. Typical design approaches first evaluate the application, make decisions about architecture and design methods, and then focus on the design's implementation. As requirements change, the design team adapts the implementation rather than re-

a service domain, such as an operating system, that is already implemented and provides the required capabilities.

With the application and service analysis complete, you can begin examining the software architecture. The service analysis yields requirements on the types and amounts of data that the system must handle and the events and timing that affect data handling. Then, in light of these requirements, the architecture analysis examines issues such as languages, platforms, and operating systems; data organization and flow control; and synchronization. The architecture analysis produces descriptions of mechanisms, which are functional capabilities the programmer must provide. The analysis also describes structures that provide rules for implementing the service processes in code.

The final step in the Shlaer-Mellor Method is to translate the process models into code following the guidelines set by the architecture's structures. In many cases, tools can automate this step.

FIGURE B



Domain analysis uses three models. The information model describes domain elements and interactions. The other models describe element behavior and the processes that manifest that behavior.

MEASURING YOUR SOFTWARE DEVELOPMENT'S MATURITY

The Software Engineering Institute (SEI) of Carnegie-Mellon University has developed a method for assessing an organization's ability to produce high-quality software. The assessment ranks a company's development process from among five levels of a Capability Maturity Model (CMM) (**Ref 6**). For many organizations, conducting the SEI assessment is the first step toward improving their software development.

Level 1, *initial*, uses ad hoc methods. Few, if any, of the steps have formal definitions. Software quality and design productivity vary considerably, depending mainly on individual effort.

Level 2, *repeatable*, uses basic project-management techniques to track project cost and schedule and assess the developed software's functional capabilities. Enough process discipline is in place to repeat successes in similar projects.

Level 3, *defined*, is documented, standardized, and integrated into an organizationwide effort.

Level 4, *managed*, involves collecting and evaluating process and software-quality measurements to actively control software development. Project managers quantitatively understand the software product and the development process.

Level 5, *optimizing*, employs continuous process improvement by using quantitative feedback from process metrics to modify the process.

Some Software Productivity Research estimates place 85% of enterprises at Level 1, 10% at Level 2, 3% at Level 3, 1.5% at Level 4, and a scant 0.5% at Level 5, the best in the class.

Although the correlation between a company's software quality and its CMM level is not exact, the model does provide a general indication of an organization's chances for producing error-free software within time and cost constraints.

TABLE 1—ORIGINS OF SOFTWARE ERRORS

Defect origins	Defect potentials	Removal efficiency	Delivered defects
Requirements	1	77%	0.23
Design	1.25	85%	0.19
Coding	1.75	95%	0.09
Document	0.60	80%	0.12
Bad fixes	0.40	70%	0.12
Total	5	85%	0.75

examining the methods or architecture. The resulting code is choppy and difficult to maintain. The project becomes dependent on "gurus" who know the details of the entire project.

Such methods fail when project complexity becomes too great for a single person to apprehend and quality suffers. Even if you divide the project into independent, manageable sections, the code quality becomes erratic. The situation is similar to building a road by assigning a different engineer and construction team to each mile. You could end up with a four-lane highway alternating with sections of dirt and gravel road.

Because traditional methods fail on large and variable projects, companies are increasingly turning to object-oriented-analysis design practices that separate architectural and implementation decisions from the application design. By separating the project into such independent domains, the design team can create and debug the application design before committing the design to coding.

At least one such object-oriented-analysis project approach, the Shlaer-Mellor Method, has reached the market with support from a variety of commercial tool vendors. (See **box**, "The Shlaer-Mellor Method.") Cadre Technologies, Objective Spectrum, and Scientific and Engineering Software offer tools that support the method. The offerings range from graphical tools that assist analysis to tools that provide automatic translation of models into code. Project Technology Inc provides training and project-management tools for the method.

High cost yields quick pay-back

You can adopt the strict formalism of object-oriented-analysis or aspire to a more traditional, but managed, development process. In either case, the effort to establish a quality software program is probably more than you can muster at the departmental level. To be successful, the effort must be part of a corporate commitment to software quality. The effort requires a combination of tools, training, and changes in management practices as well as substantial time and cash investments. Estimates from SPR indicate that for an organization to go from a Level 1 company to a world-class software vendor takes three years of hard work. The estimated cost of such a move is more than $30,000 per software-staff member for tools and training.

Such investments, however, pay off fairly quickly. Operating-system provider Microware Systems Corp took two years to build its quality program and attain ISO-9000 certification. Product development now takes less effort, and the company spends less time in maintenance. The improved development efficiency and resource shift from maintenance to development has greatly increased Microware's ability to develop and sell new products. Raytheon's equipment division also invested more than $1 million in improved software quality. Since 1988, the company has seen a return of $7.80 in reduced rework costs for every dollar spent upgrading its methods.

Quality efforts also result in individual payoffs. You get to spend more time designing new products and less time fixing old ones. You also get to hold your head a trifle higher because people no longer laugh when you say "software quality." EDN

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(continued on pg 81)

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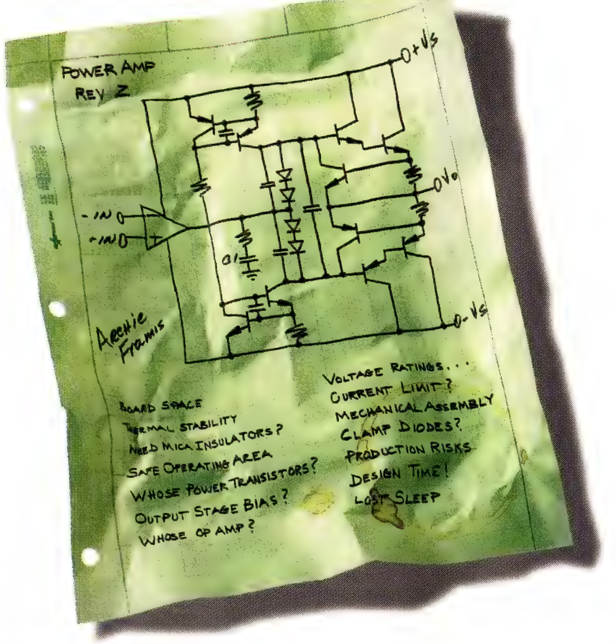

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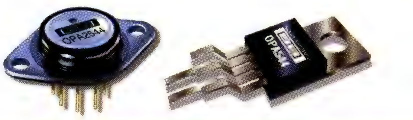

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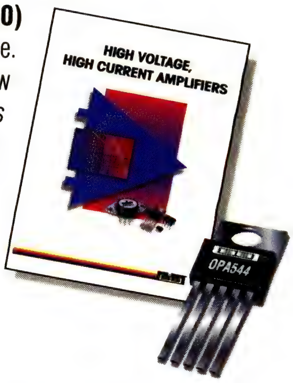

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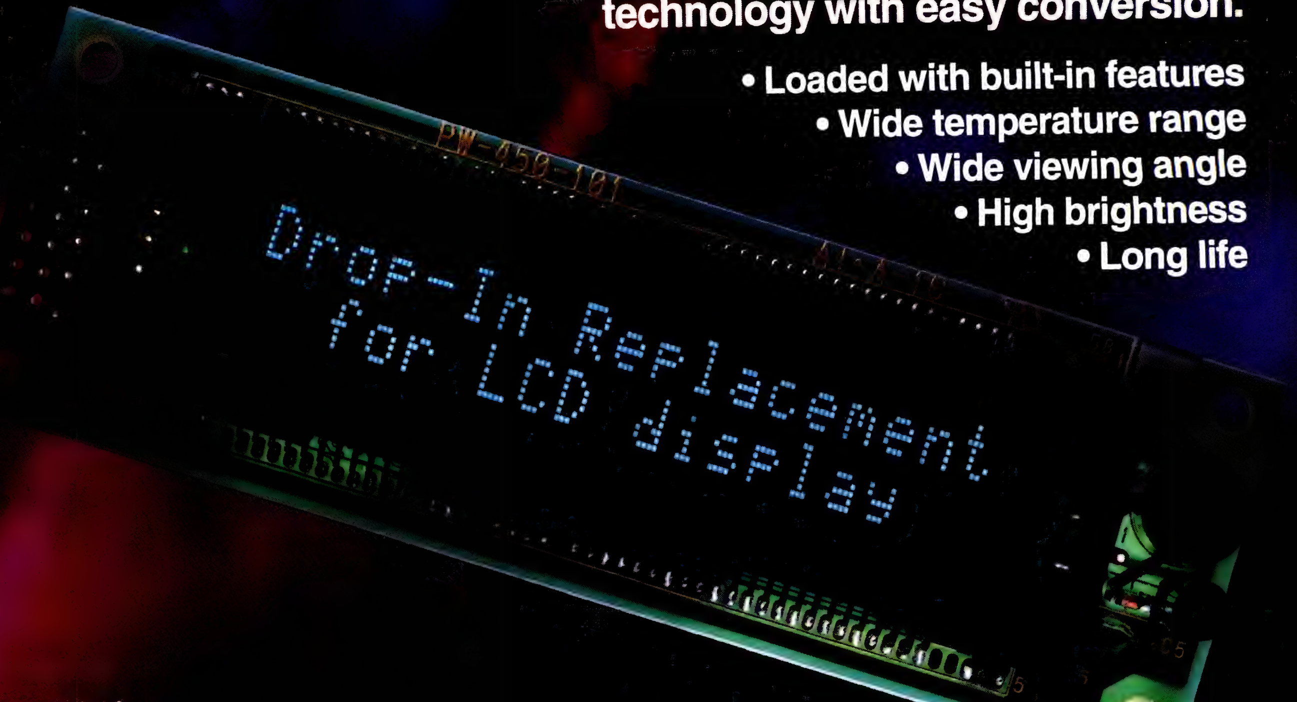

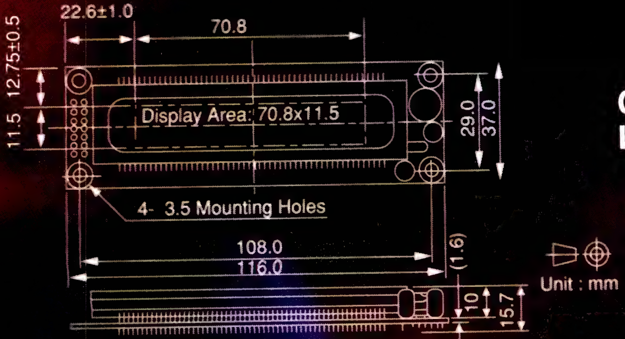

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CIRCLE NO. 229

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CIRCLE NO. 36

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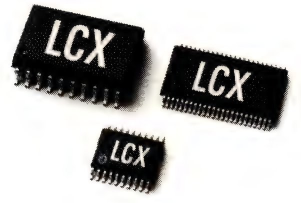

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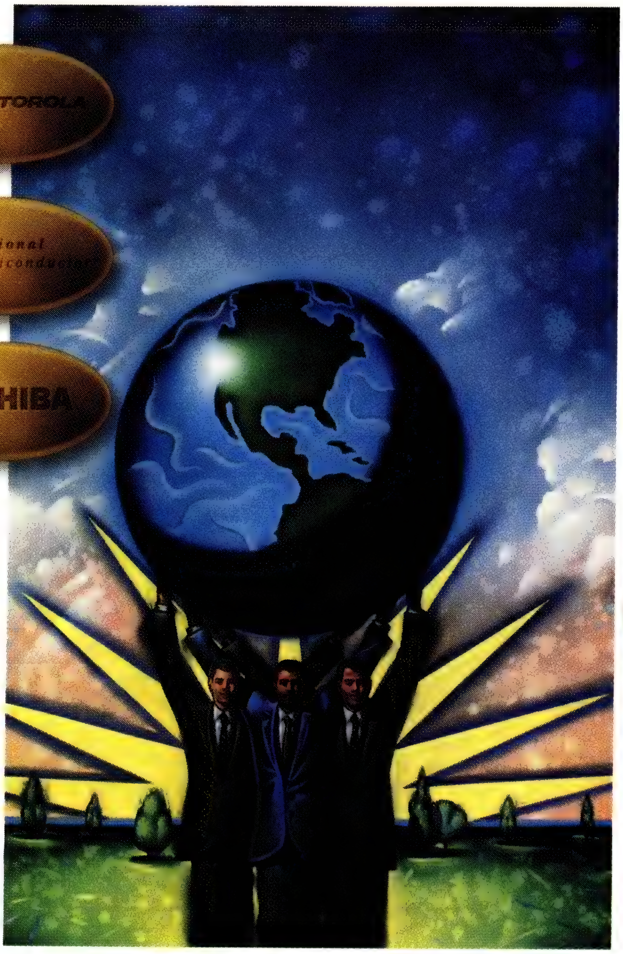
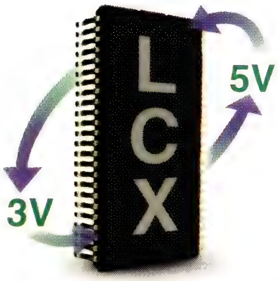


Two. The new standard for low voltage logic is the LCX family of CMOS 3.3V logic[1] The LCX family consists of a wide range of devices that offer an excellent combination of 5V to 3.3V translation, speed, low power and low cost.



The LCX family of low voltage logic from Motorola, National, or Toshiba offers remarkable translation capability: 3.3V CMOS devices with 5V tolerance on both inputs and outputs.

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Four. The LCX family offers the most popular logic functions; including gates, MSI, 8-bit & 16-bit devices. Packaging options include SOICs, SSOPs and TSSOPs.

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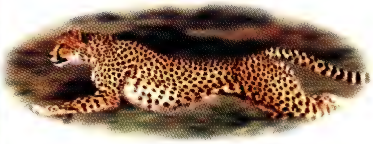

Proof that low power doesn't have to mean low speed, the LCX family zips along at a formidable 4.5ns to 6.5ns max propagation delay.

THE LOW VOLTAGE LOGIC ALLIANCE

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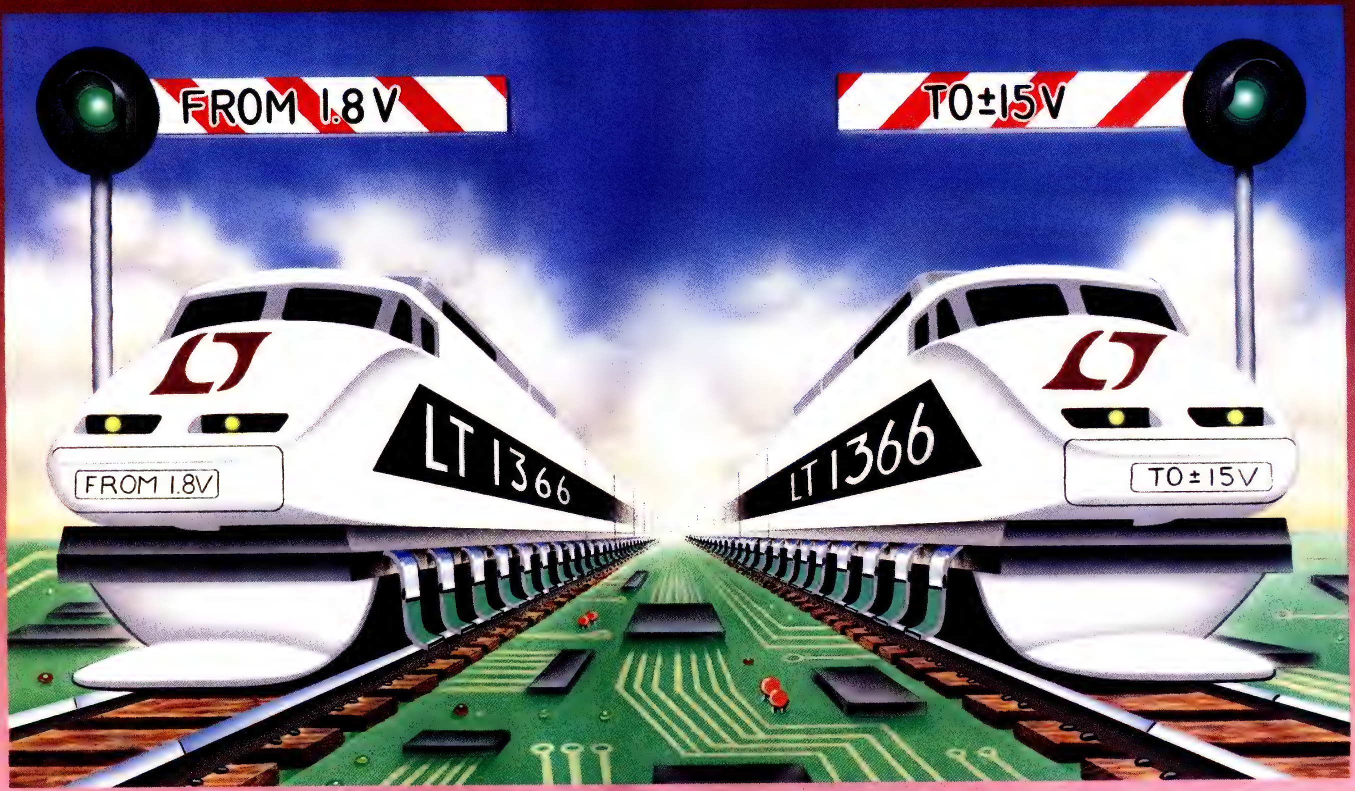
CIRCLE NO. 147

No Compromise Rail-To-Rail Op Amps.



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The LT1366 dual and LT1367 quad are stable at all gains with load capacitances up to 1000pF. The LT1368 dual and LT1369 quad are optimized for driving capacitive loads of 0.05μF to 1μF.

LT1366/68 Guaranteed Performance Chart

	Vs = 3V	Vs = ±15V
Max V_{OS}, Rail-to-Rail	475μV	700μV
Max I_B, Rail-to-Rail	35nA	35nA
Max I_{OS}, Rail-to-Rail	6nA	6nA
Min A_{VOL}	500k	2000k
Min Output Swing, No Load	2.980 Vpp	29.980 Vpp
Min Output Swing, I_{OUT} = 2.5mA	2.550 Vpp	29.550 Vpp
Min I_{OUT}	±10mA	±30mA
Max I_{SUPPLY} (per amp)	500μA	550μA

The LT1366/8 dual op amps are available in 8-pin SO or 8-pin mini-DIP packages. The LT1367/9 quad op amps are available in narrow (150mil) SO16 surface mount packages. Pricing starts at $3.46 in quantities of 1000.

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Battery charger indicates rate of charge

LARRY SUPPAN, MAXIM INTEGRATED PRODUCTS, SUNNYVALE, CA

A single LED indicates whether the battery charger in **Fig 1** is delivering a trickle charge or a fast charge. During fast charges, the LED stays lit continuously because IC$_2$'s $\overline{\text{FASTCH}}$ output sinks dc. During trickle charges, the LED flashes because D$_1$ and Q$_1$ enable the 555 timer. The timer is an astable multivibrator operating at 60 Hz (f=1/1.4RC).

The timer remains enabled during a fast charge, but it must shut off upon disconnection of the battery. Zener diode D$_1$ makes that decision. With no battery connected (a condition that R$_5$ and an internal comparator sense), IC$_2$ produces a voltage at BATT+ equal to twice the number of cells for which the IC is programmed. This voltage (4V for two cells) turns on the 3.3V zener diode and disables the timer.

Connecting a battery drops the BATT+ voltage to 2.8V (1.4V per cell), thereby turning off D$_1$ and Q$_1$, and enables the timer. The timer's output drives Q$_3$, whose collector (in a wired-OR connection with the open-drain $\overline{\text{FASTCH}}$ output) causes the LED to flash. Other cell counts require different zener voltages (**Table 1**).

During a fast charge, the LED should glow steadily, without flicker that would occur if the timer were operating. This continuous-glow condition is assured if the $\overline{\text{FASTCH}}$ voltage remains low: IC$_2$'s data sheet guarantees 0.4V max when $\overline{\text{FASTCH}}$ sinks 2 mA. Higher currents produce a higher voltage, which may result in flicker. In that case, you can cure the problem by adding a resistor in the emitter of Q$_3$. (DI #1705)

TABLE 1—ZENER-DIODE VOLTAGE VS CELL COUNT

Cell count	BATT+ voltage (V)	Charged-battery voltage (V)	Required zener voltage (V)
2	4	2.8	3.3
4	8	5.6	6.8
6	12	8.4	10
8	16	11.2	15
10	20	14	18
12	24	16.8	18
14	28	19.6	24

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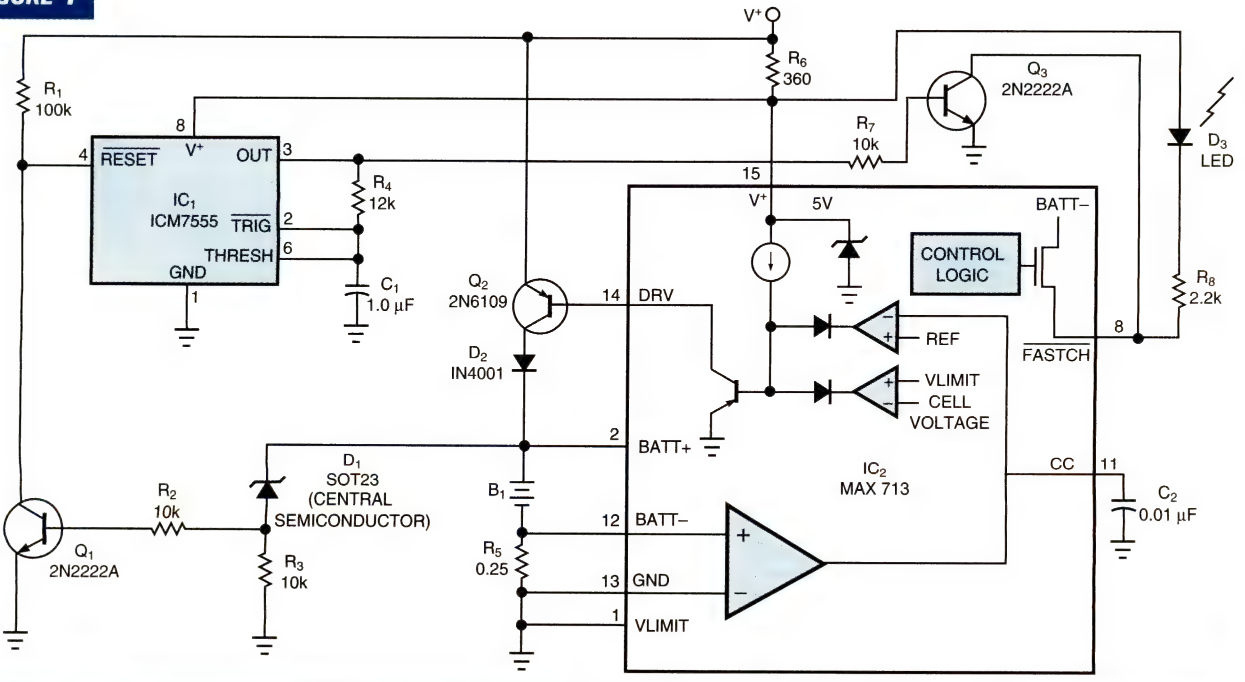
FIGURE 1



The shaded components in this charger for NiCd or nickel-metal-hydride batteries cause the LED to flash during trickle charges and to glow continuously during fast charges.

Remote charging circuit uses three-wire sensing

D HAYDEN, TEMPO RESEARCH, VISTA, CA

Remote voltage sensing usually uses a four-wire sensing system, which involves two conductors for high load-current flow and two high-impedance paths for accurately measuring the remote voltage without incurring substantial ohmic losses. Voltage control at the load, therefore, entails measuring the "sense" pair and driving the "output" pair. Over cables in which the impedances in the source and return paths to the load are equal, you can use a three-wire sense system, thereby saving a conductor.

The circuit in **Fig 1** takes advantage of equal resistance in the source and return paths. It uses a simple network to sense the remote voltage and drive the output to precisely control the remote voltage. In the output network, R_L represents the resistance of a single cable conductor, for example, 4Ω for 100 ft of #26 wire. V_O is the output voltage to the cable, with reference to the return lead (GND). V_S is the voltage of the sense lead, with reference to the return lead (GND).

V_L is the desired voltage at the load, and I_O is the current flowing through the cable and load. I_S is the current flowing through the sense lead, designed such that $I_S \ll I_O$. Z_L is the load impedance. Assuming all equations have GND as reference, if $V_S = I_O R_L + I_O Z_L$, $V_L = I_O Z_L$, and $V_O = 2I_O R_L + I_O Z_L$, then $V_O = 2V_S - V_L$. By setting the desired voltage setpoint, $V_{LSETPOINT}$, using a manual adjustment or control input, you can control V_O to make $V_L = V_{LSETPOINT}$.

You may have to attenuate the sense voltage and control voltage with added gain in the output control loop to maintain an acceptable common-mode range for the processed signals in the amplifiers (**Fig 2**). Be careful to maintain high impedance in the sense circuit. Insofar as the regulating supply voltage has enough compliance, the circuit maintains proper operation with changes (such as those caused by heating) in the cable's conductor resistance. (DI #1706) EDN

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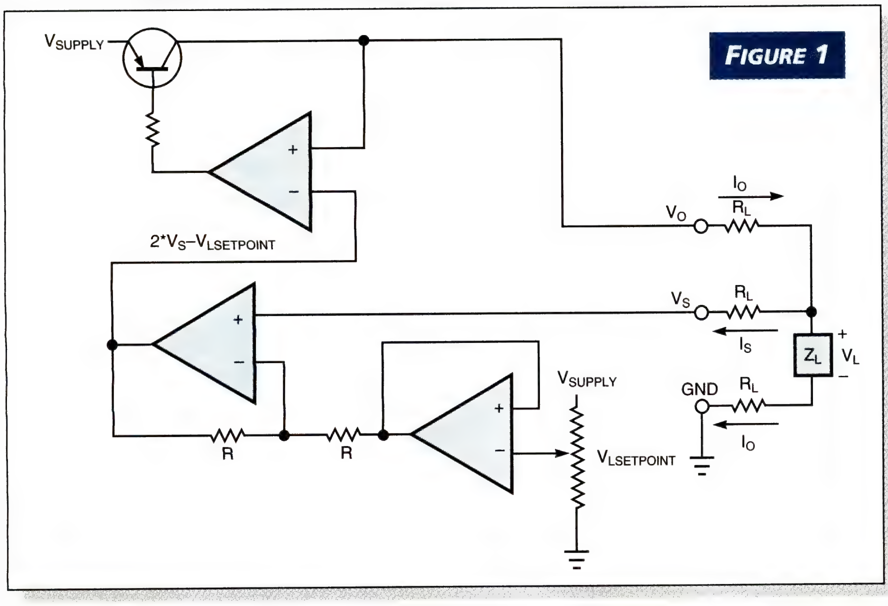
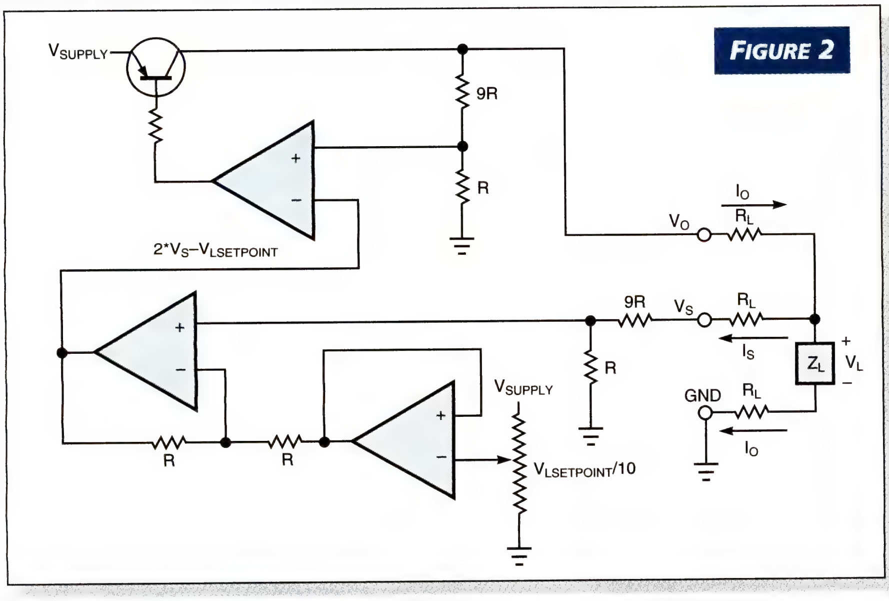


When the source- and return-path impedances are equal, you can use this three-wire sensing arrangement to remotely measure and control the load voltage.



Adding attenuation and gain to the circuit in Fig 1 maintains acceptable common-mode range in the processed signals in the amplifiers.

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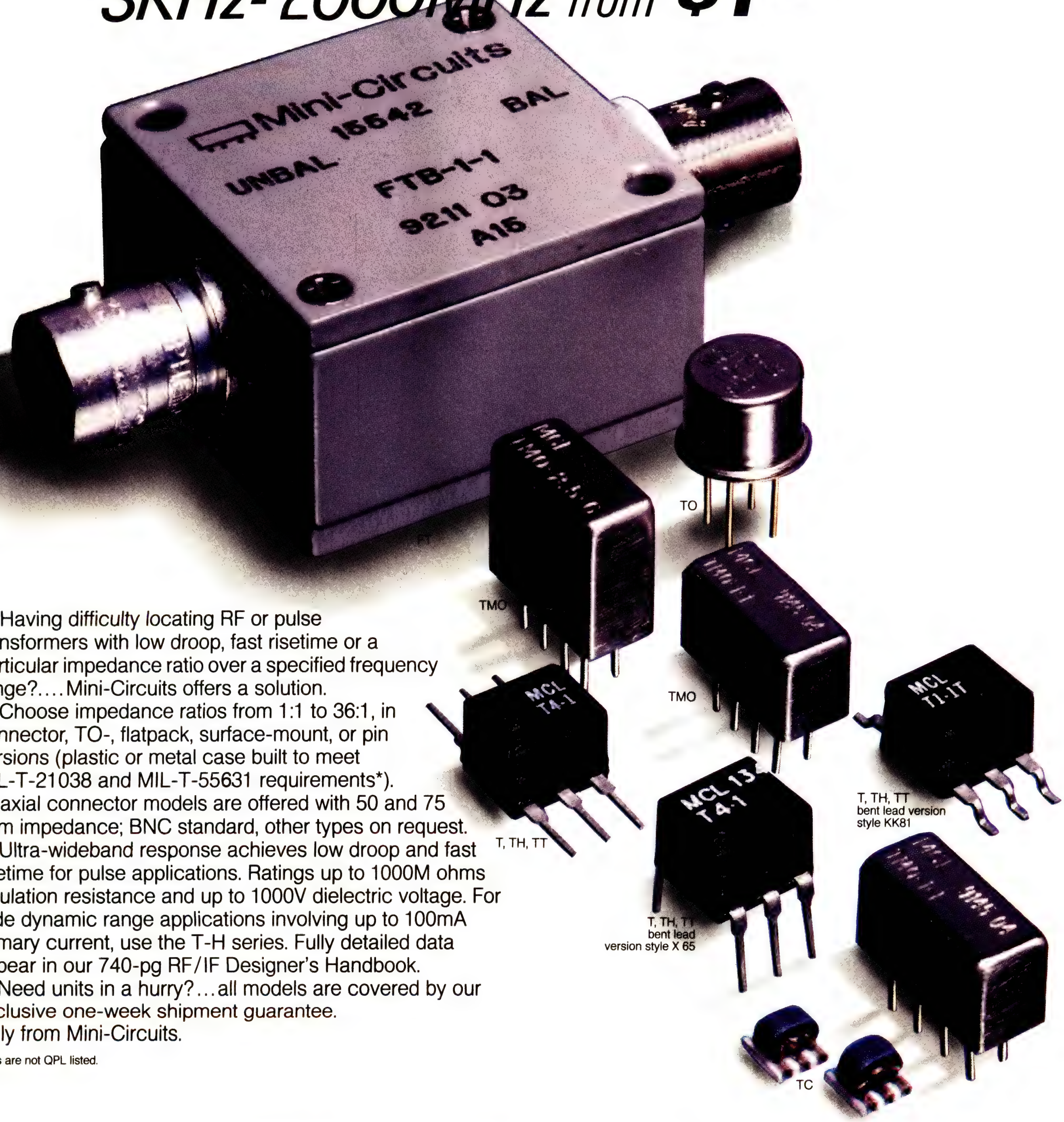

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CIRCLE NO. 185

Analog switch cuts peak-detector reset time

GUALTIERO BOLOGNESI, LANDIS & GYR, PESCHIERA BORRONMEO, ITALY

The schematic in **Fig 1** is a basic configuration for a unity-gain peak detector using the PKD-01FP monolithic peak detector from Analog Devices. The reset time, t_{RES}, is the time necessary to discharge the hold capacitor C_H. t_{RES} and the acquisition time t_{ACQ} are functions of the IC's output-current capability. With C_H=10 nF, this output-current limitation sets both t_{RES} and t_{ACQ} to about 220 μsec.

You can obtain fast resetting, independent of the IC's output capability, by adding an analog switch in parallel with the hold capacitor (**Fig 2**). The p-channel JFET, Q_1, buffers reset pulse V_{RES} to provide the needed V_{GS} drive level to the n-channel JFET, Q_2. Pullup resistor R_1 guarantees an off condition for Q_1 ($V_{GS(OFF)}$=4V max) with a high output in the CMOS logic block. When Q_2 turns on and discharges C_H, the discharge time constant is $t_{DIS}=C_H \cdot r_{DS(ON)}$=600 nsec, assuming a maximum value of 60Ω for Q_2's on-resistance at 25°C. Assuming a minimum reset-pulse duration of about five times the discharge time constant, the reset time is 3 μsec.

When Q_2 turns off, the drain cutoff current, $I_{D(OFF)}$, introduces a droop rate given by
assuming a conservative maximum value of 250 pA for $I_{D(OFF)}$.

$$\frac{dV_{CH}}{dt}=\frac{I_{D(OFF)}}{C_H}=\frac{250\ \text{pA}}{10\,\text{nF}}=25\ \mu\text{V/msec},$$

Q_2 introduces this additional droop rate, which is about one-eighth of the droop rate stemming from the PKD-01FP peak-detector IC. The use of a 2N4392 n-channel JFET for Q_2, whose $I_{D(OFF)}$=100 pA, reduces the additional droop rate to one-twentieth the PKD-01FP contribution. (DI #1708)

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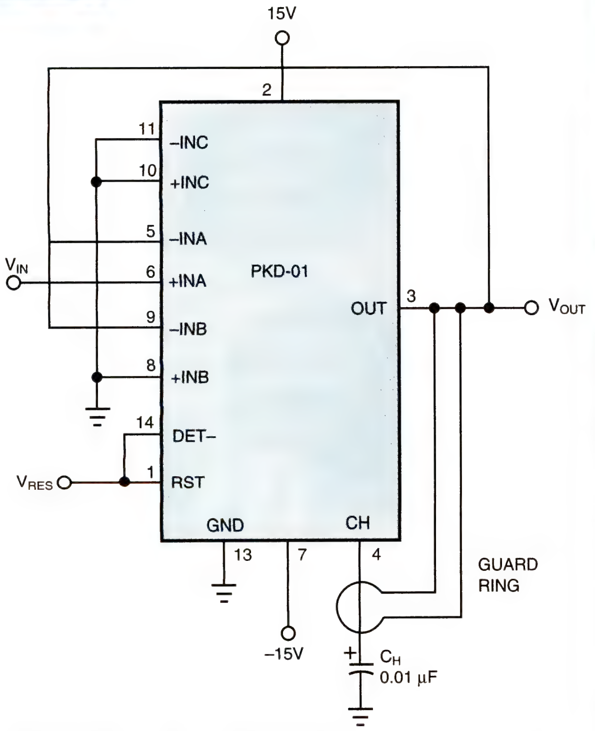
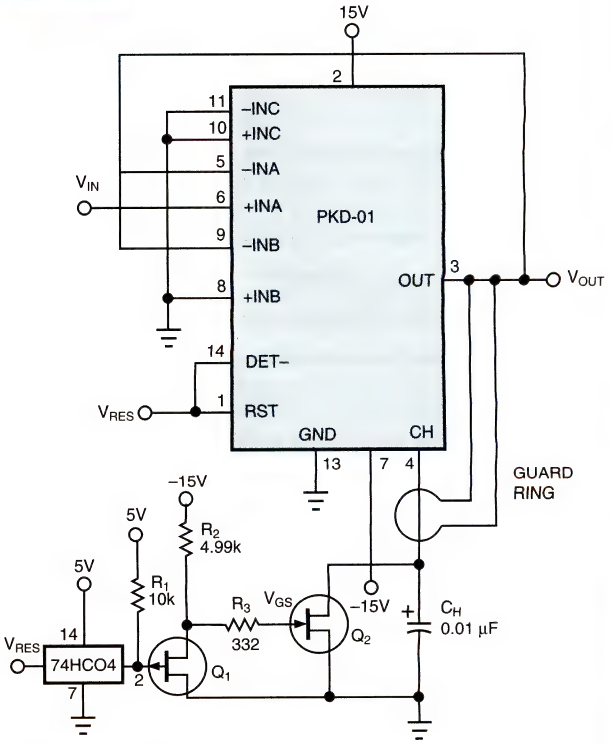
FIGURE 1



In this unity-gain, peak-detector configuration, the discharge current available to the hold capacitor sets the reset time to about 220 μsec.

FIGURE 2



The JFET analog switch, Q_2, rapidly discharges the hold capacitor and thus lowers the reset time to about 3 μsec.

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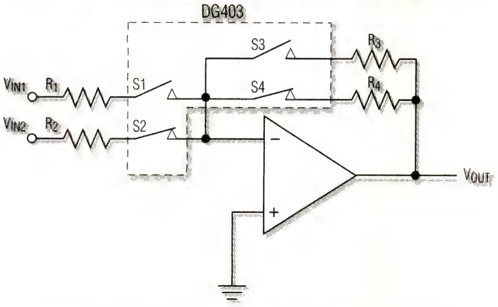

Switching into a virtual ground reduces distortion caused by $r_{DS(ON)}$ variation over the analog signal range. Guaranteed $r_{DS(ON)}$ matching (typically 0.5Ω) ensures gain accuracy of <0.01% when R1 through R4 are greater than 10kΩ.

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DG421/3/5	3	4	15	5	10
DG441/2/4/5	3	9	10	5	10

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North American inquiries, Circle No. 157

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IC forms differential line driver/receiver

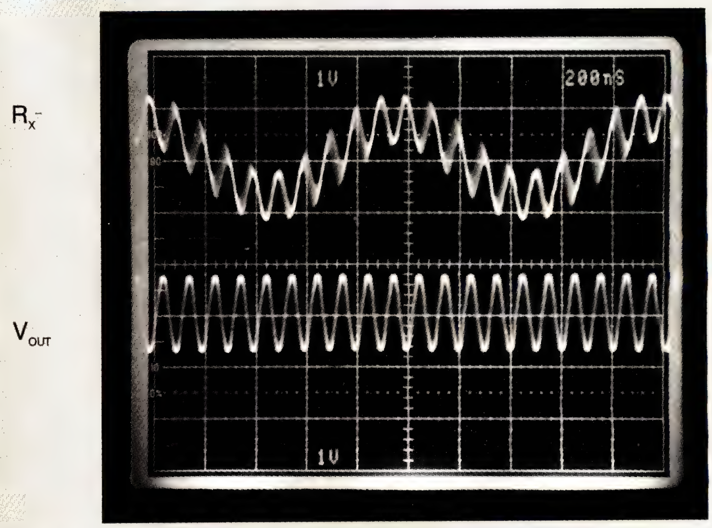
MARK AMARANDOS, HARRIS SEMICONDUCTOR, COSTA MESA, CA

You can use the HFA1212 dual video buffer to implement differential line drivers and receivers (**Fig 1**) with a minimum of external components. Common-mode rejection is a function of the internal matched thin-film resistors, which you can pin-strap to set the required loop gains. V_{IN} terminates in 75Ω and drives both amplifiers in IC_1. IC_{1A} and IC_{1B} have gains of –1 and +1, respectively. These amplifiers create a differential signal with a net gain of two. The 75Ω series resistors at the outputs provide impedance matching to the transmission line.

The 150Ω resistor on the receiver side of the transmission line provides proper impedance matching and attenuation for a gain of one at the receiver input. IC_2 performs differential-to-single-ended conversion and provides common-mode rejection. IC_{2A} is configured for a gain of +2. IC_{2B} subtracts common-mode signals and provides a gain of +2 to differential signals. When V_{OUT} terminates in 75Ω, the overall gain from V_{IN} to V_{OUT} is unity. Because of the gain of +2 in IC_{2A}, the peak voltage at the receiver may not exceed 1.5V.

The oscilloscope photo in **Fig 2** shows the common-mode rejection of the receiver. V_{IN} is a 10-MHz, 1.5V p-p sine wave. A 1-MHz, 1.5V p-p common-mode signal drives the ground reference of **Fig 1**'s IC_1 (with respect to the ground of IC_2). The upper trace shows the combined signal that appears at R_X–. V_{OUT}, seen in the bottom trace, is a faithful reproduction of V_{IN}, with the common-mode signal removed. (DI #1709)

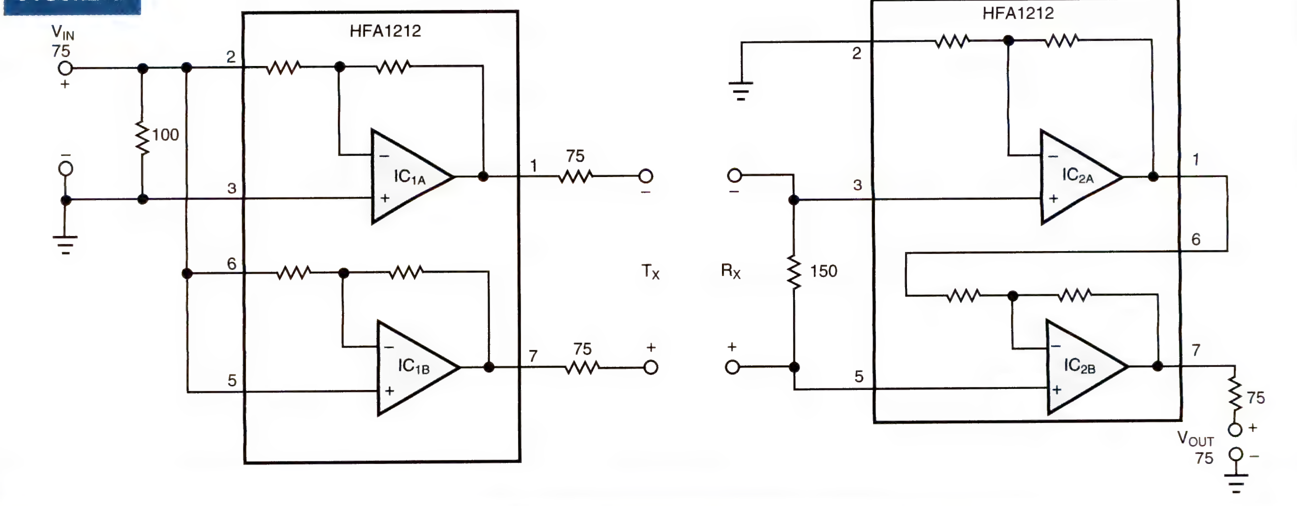
FIGURE 2



The receiver circuit of Fig 1 subtracts the 1-MHz common-mode signal in the top trace, to provide a faithful reproduction of the 10-MHz input signal.

To Vote For This Design, Circle No. 318

FIGURE 1



A dual video-buffer IC and a few resistors form a differential video line driver or receiver with a high common-mode rejection ratio. The external resistors provide impedance matching for the 75Ω transmission line.

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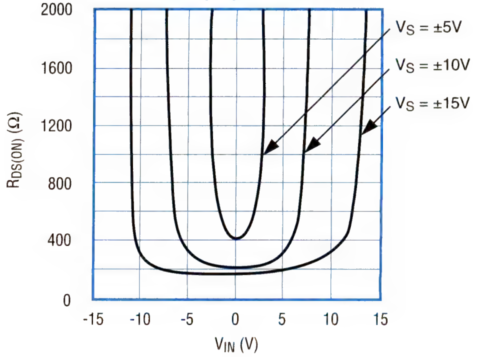
MAX354

$R_{DS(ON)}$ vs. V_{IN}



Using a series N-channel, P-channel, N-channel structure, these multiplexers significantly improve fault protection. When signal voltages exceed or are within 1.5V of the supply rails, on-resistance increases, limiting fault currents as well as output voltage. This protects sensitive circuits and components on both sides of the switch.

PARAMETERS	MAX354/ MAX355	MAX358/ MAX359	ADG508F/ ADG509F	DG508A/ DG509A
Fault Protection (V)	±40	±35	±35	None
Overvoltage Protection (V)	±40	±35	±35	None
Channel On-Resistance (Ω)	350	1,800	400	400
Channel Off Leakage (pA)	500	1,000	1,000	1,000
Channel On Leakage (pA)	500	5,000	1,000	10,000
Transition Time (ns)	250	1,000	300	1,000
Price* ($)	2.45	2.45	3.35	2.39

* 1000-pc recommended resale, FOB USA.

Features:

- **Self Protection:**
  Muxes survive ±40V overvoltage with no external components
- **Output Protection:**
  Output clamps at $|V_S - 1.5V|$ during input overvoltage
- **System Operation Maintained:**
  Mux output not affected by overvoltage to any off channel

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North American inquiries, Circle No. 155

European inquiries, Circle No. 156

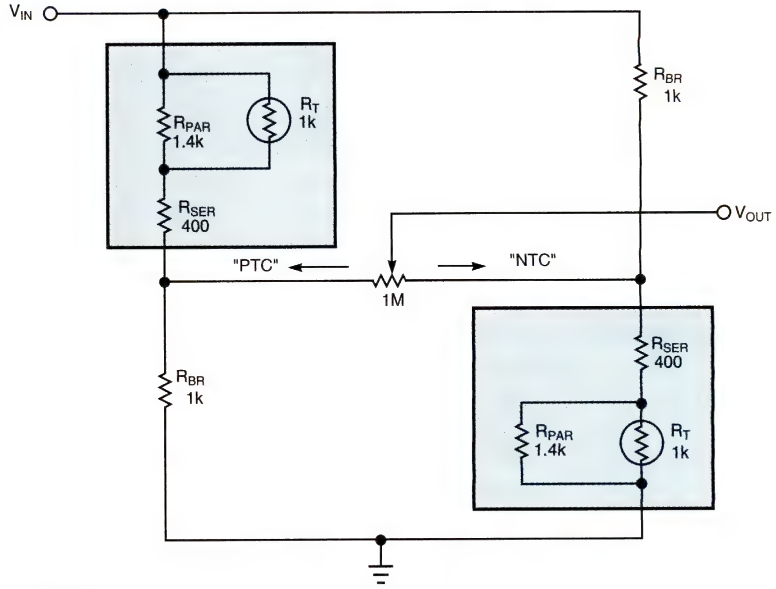
Universal compensator neutralizes temperature coefficient

ALEXANDER BELOUSOV, STANDARD MOTOR PRODUCTS, LONG ISLAND CITY, NY, (718) 392-0200

The universal thermal-compensation module in **Fig 1** can neutralize the temperature coefficient of both signs within a ±0.6%/°C range. The circuit can compensate the temperature coefficient of offset voltage, gain, sensitivity, or, in general, the linear terms of a device's overall temperature behavior. The circuit consists of a pair of negative-temperature-coefficient (NTC) thermistors, labeled R_T, and of fixed resistors with calculated values that reduce the inherent nonlinearity of the thermistors. Because of this linearization, the overall nonlinearity stays within ±1.2% for a 0 to 50°C temperature range.

When the 1-MΩ potentiometer is in the maximum left position, the TC has a maximum positive value of 0.6%/°C. In the maximum right position, the circuit produces maximum NTC of the same absolute value. You can continuously adjust the TC between these two extremes. For proper operation, good thermal contact is necessary between the module (the thermistors, primarily) and the device that you're compensating. The TC of the circuit depends only on the wiper position—not on the input voltage. So, you can adjust the output voltage and TC independently. The module has a gain of 0.5 at 25°C.

FIGURE 1



NOTE:
R_T=NTCCS32163BH102KC OR NTCCS20123BH102KC, TDK CORP OF AMERICA.

Fig 1—This thermal-compensation module reduces an external circuit's temperature coefficient to within a ±0.6%/°C range.

The resistor values in **Fig 1** are the exact calculated numbers that provide the best linearization. These values are feasible in film technology with laser trimming. For discrete components, you simply have to choose the closest values. The circuit uses inexpensive, chip-NTC thermistors with nominal values of 1k at 25°C and constant B=3100, but any other types are applicable. However, differences in constant B may cause slightly higher nonlinearity. The power consumption of a thermistor is $\le 0.1\times V_{IN}^2$ mW. This power has to be small enough to avoid the self-heating of the thermistor body. In most practical cases, V_{IN} varies from 1 to 10V, so the power varies from 0.1 to 10 mW.

Performing the compensation requires that you first measure the output of the device at room temperature with the wiper electrode close to the center. Then, heat or cool the device to either a minus or plus temperature close to the margins, such as 0 and 50°C. Make the TC adjustment by rotating the wiper so that the error decreases. The criterion of compensation is simple: The output of the device at temperature extremes should be the same as the room-temperature output.

Strictly speaking, this module can compensate only the linear part of the initial TC of a device. Residual TC of the device is 90% less than initial. The circuit can actually operate over a –25 to +85°C temperature range, but was optimized for a 0 to 50°C operating range. You may see increasing nonlinearity outside of this range. A special program can estimate the nonlinearity in any temperature range and can calculate the proper values of the resistors. (The program is available from the author.)

For precise compensation, a reduced range of TC is preferable. Choosing $R_{PAR}=800\Omega$, $R_{SER}=2.5\ k\Omega$, and $R_{BR}=3\ k\Omega$ reduces the full range of TC to ±0.1%°C. (DI #1703) EDN

To Vote For This Design, Circle No. 319

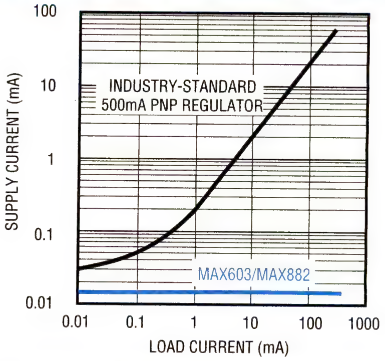
WORLD'S SMALLEST 500mA REGULATOR USES 15µA QUIESCENT AT ALL LOADS

Small, High-Power 8-Pin SOIC Dissipates Up to 1.8W—*Extends Operating Range*

The MAX603/MAX882 family of linear regulators uses P-channel MOSFET transistors and high-power packaging to reduce size, increase battery life, and extend operating range. Maxim's P-channel design keeps supply current low, even at high output current and at low input-to-output differentials where the PNPs in bipolar low-dropout regulators saturate.

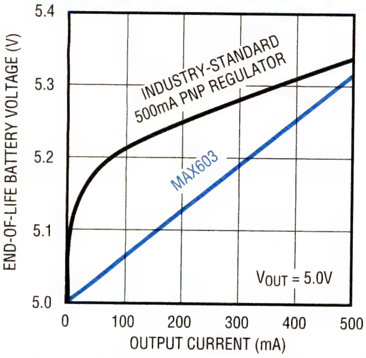
- **1.8W High-Power 8-Pin SO Package**
- **15µA Supply Current at I_{OUT} = 500mA**
- **2µA Shutdown Current**
- **2.7V to 11.5V Input Voltage Range**
- **1.3V to V_{IN} Output Voltage Range**
- **Low Dropout Voltage (320mV at 500mA)**
- **Thermal Shutdown, Reverse Current & Short-Circuit Protection**
- **500mA (MAX603/MAX604)**
  200mA (MAX882/MAX883/MAX884)

LOWEST SUPPLY CURRENT AT ALL LOADS



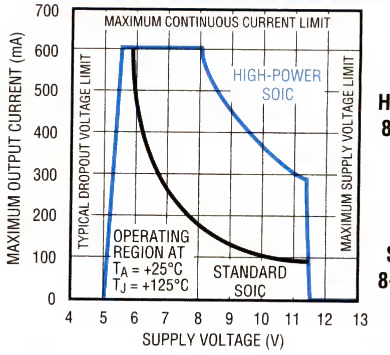
Maxim's P-channel design draws only 15µA, unlike bipolar low-dropout regulators, which consume up to 60mA at full load and waste up to 0.5W of additional power.

LOWEST DROPOUT VOLTAGE



Low dropout voltage extends useful battery life.

HIGHEST POWER IN AN SO-8



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Standard 8-Pin SOIC 0.47W

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North American inquiries, Circle No. 153

European inquiries, Circle No. 154

Universal watchdog fully controls µP reset

TERJE KVINGE, NERA AS, KOKSTAD, NORWAY

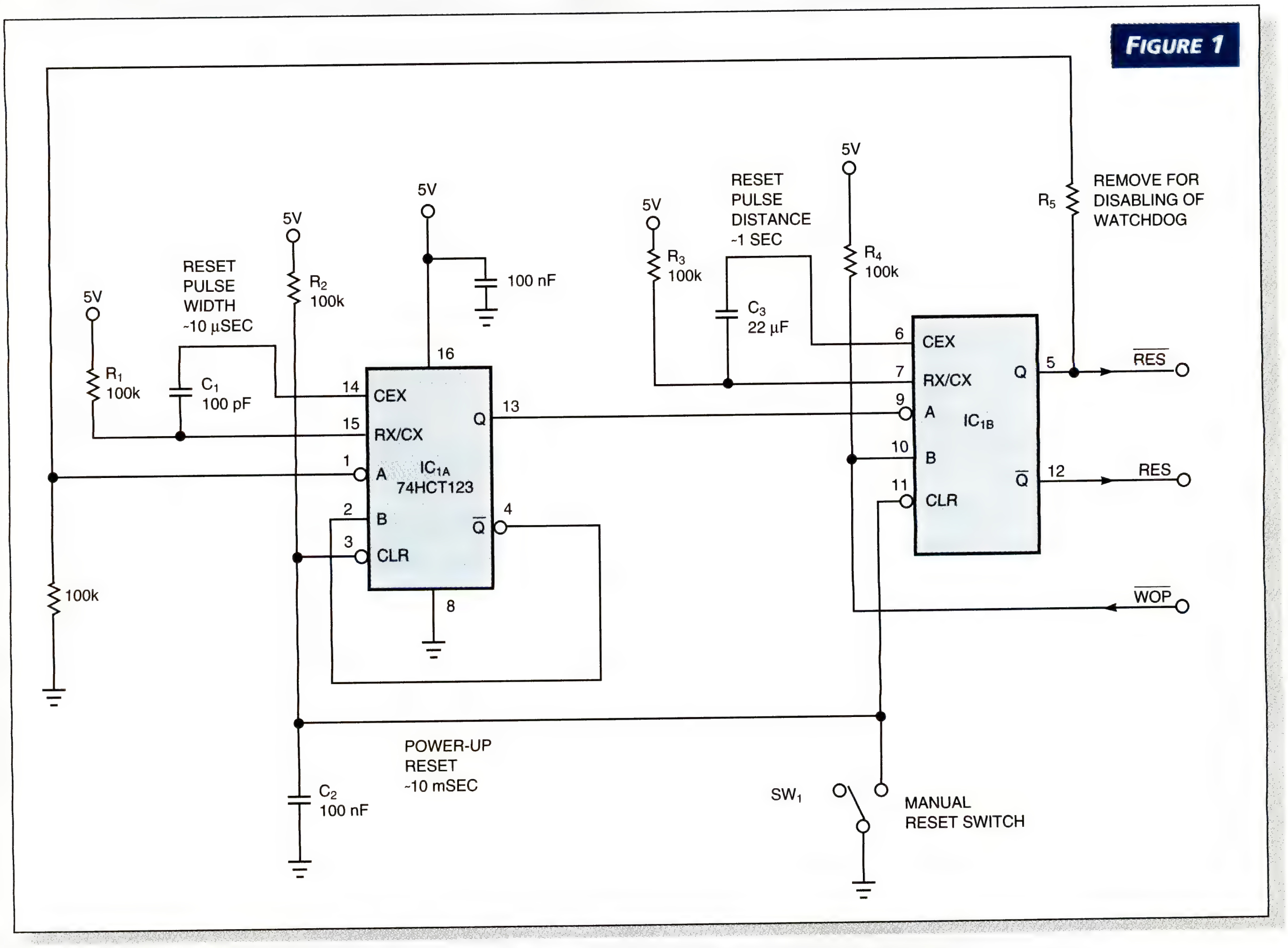
Many µPs contain internal watchdog timers, and you may wonder why you need another stand-alone circuit. Unfortunately, more highly integrated functions have preset parameters that you may want to change. Also, internal watchdogs are generally a simple combination of a flip-flop and a timer. If the program does not start properly on the first try, the timer is of no use because the program never turns on the watchdog. This watchdog catches *exactly* this condition.

The design in **Fig 1** allows you to set all parameters and fully control the reset of the µP. The circuit consists of two serially coupled one-shots in IC_1. IC_{1A} controls the reset pulse width using R_1 and C_1, and IC_{1B} controls the distance between pulses using R_3 and C_3. The µP should apply a short negative pulse to the watchdog input at R_4. If this signal is static long enough and enables IC_{1B} to time out, the circuit returns a reset pulse. At power-up, the circuit activates reset for a longer time using R_2 and C_2, enabling the processor clock to stabilize. Pushing SW_1 performs a manual reset. You can also disable the watchdog function by removing R_5 if special testing is necessary, such as when you implement the WDPulse for the first time. In this mode, IC_{1A} retriggers itself, disabling IC_{1B}.

This design uses cheap, off-the-shelf components, is flexible, is reliable, and has moderate power consumption of approximately <2 mA. The one thing missing is a supply-voltage monitor. You can add one using an ordinary op amp or a simple IC, such as the MAX809. You can simply insert this IC between 5V and R_3. (DI #1704) EDN

To Vote For This Design, Circle No. 320

FIGURE 1



This universal watchdog timer allows you to set all parameters and fully control a µP's reset.

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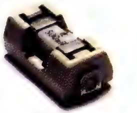
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CIRCLE NO. 149

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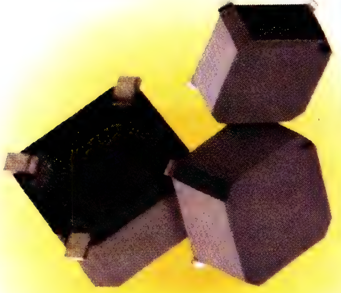

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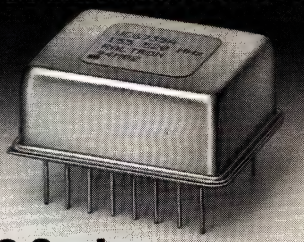

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The winning Design Idea for the October 27, 1994, issue is entitled "Peltier element controls itself," submitted by Dmitrii Loukianov of Intel Corp (Moscow, Russia).

LINEAR TECHNOLOGY

DESIGN NOTES

LTC1410: 1.25Msps 12-Bit A/D Converter Cuts Power Dissipation and Size – Design Note 104

Dave Thomas and Kevin R. Hoskins

Introduction

Until now, high speed system designers had to compromise when selecting 1Msps 12-bit A/D converters. While hybrids typically had the best performance, they were big, power hungry (~1W) and costly (>$100). A few manufacturers offered monolithics, but they compromised either AC or DC performance.

That has now changed. The new LTC®1410 monolithic 1.25Msps 12-bit ADC performs better than hybrids with the power dissipation, size and cost of monolithics.

Some of the LTC1410's key benefits include:

- 1.25Msps throughput rate
- Fully differential inputs
- 60dB CMRR that remains constant to 1MHz
- Low power: 160mW (typ) from ±5V supplies
- "Instant on" NAP and μpower SLEEP shutdown modes
- Small package: 28-pin SO

The LTC1410's features can increase the performance and decrease the cost of current data acquisition systems and optimize new applications.

High Accuracy Conversions: AC or DC

In Figure 1 the LTC1410 combines a wide bandwidth differential sample-and-hold (S/H) with an extremely fast successive approximation register (SAR) ADC and an on-chip reference. Together they deliver a very high level of both AC and DC performance.

An ADC's S/H determines its overall dynamic performance. The LTC1410's S/H has a very wide bandwidth (20MHz) and generates very low total harmonic distortion (–84db) for the 625kHz Nyquist bandwidth.

Important DC specifications include excellent differential linearity error $\leq$0.8LSB, linearity error $\leq$0.5LSB and no missing codes over temperature. The on-chip 10ppm/°C curvature corrected 2.5V bandgap reference assures low drift over temperature.

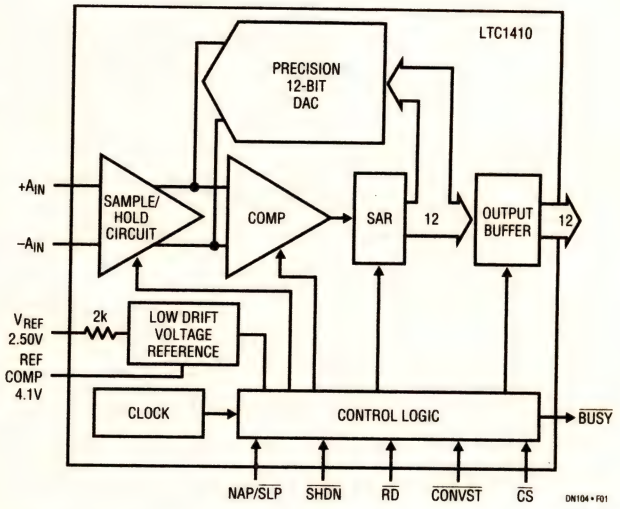

Figure 1. LTC1410 Features a True Differential S/H with Excellent Bandwidth and CMRR

If an application requires an external reference, it can easily overdrive the on-chip reference's 2kΩ output impedance.

Important Multiplexed Applications

The LTC1410's high conversion rate allows very high sample rate multiplexed systems. The S/H's high input impedance eliminates DC errors caused by a MUX's switch resistance. Also, the LTC1410's low input capacitance ensures fast 100ns acquisition times, even with high source impedance.

Ideal for Telecommunications

Telecommunications applications such as HDSL, ADSL and modems require high levels of dynamic performance. A key indicator of a sampling ADC's dynamic performance is its signal-to-noise plus distortion ratio (SINAD). The LTC1410's minimum SINAD is 72dB, or 11.67 Effective

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Circle No. 60

Number of Bits (ENOB), up to input frequencies of 100kHz. At the Nyquist frequency (625kHz) the SINAD is still a robust 70dB. Figure 2 shows that the LTC1410 can undersample signals well beyond the Nyquist rate.

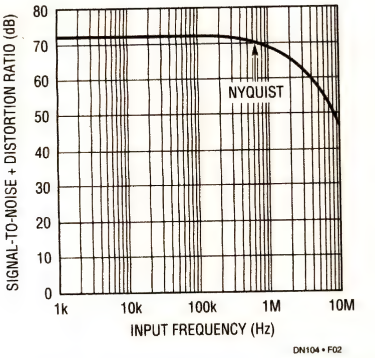

Figure 2. The Wideband S/H Captures Signals Well Beyond Nyquist

Differential Inputs Reject Noise

The LTC1410's differential inputs are ideal for applications whose desired signals must compete with EMI noise. The LTC1410's differential inputs provide a new way to fight noise.

Figure 3a shows a single-ended sampling system whose accuracy is limited by ground noise. When a single-ended signal is applied to the ADC's input, the ground noise adds directly to the applied signal. While a filter can reduce this noise, this does not work for in-band noise or common-mode noise at the same frequency as the input signal. However, Figure 3b shows how the LTC1410 provides relief. Because of its excellent CMRR, the LTC1410's differential inputs reject the ground noise even if it is at the same frequency as the desired input frequency. Further, the LTC1410's wideband CMRR can eliminate extremely wideband noise, as shown in Figure 4.

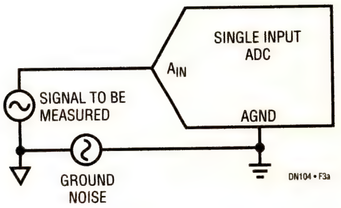

Figure 3a. An Input Signal is Contaminated by Ground Noise with a Single Input ADC

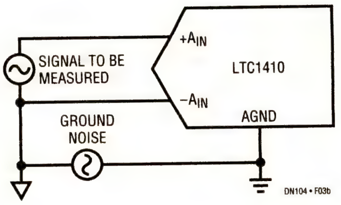

Figure 3b. The LTC1410's Differential Inputs Reject Common-Mode Noise and Preserve the Input Signal

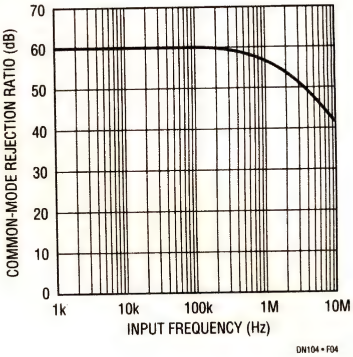

Figure 4. The LTC1410 Rejects Common-Mode Noise Out to 10MHz and Beyond

Low Power Applications

High speed applications with limited power budgets will greatly benefit from the LTC1410's low 160mW power dissipation. Power can be further reduced by using the power shutdown modes, NAP and SLEEP.

NAP reduces power consumption by 95% (to 7.5mW) leaving only the internal reference powered. The "wake-up" time is a very fast 200ns. The most recent conversion data is still accessible and $\overline{CS}$ and $\overline{RD}$ still control the output buffers. NAP is appropriate for those applications that require conversions instantly after periods of inactivity.

SLEEP reduces power consumption to less than 5µW. It is useful for applications that must maximize power savings. SLEEP mode shuts down all bias currents, including the reference. SLEEP mode wake-up time is dependent on the reference compensation capacitor's size. With the recommended 10µF, the wake-up time is 10ms. Typically, NAP mode is used for inactive periods shorter that 10ms and SLEEP is used for longer periods.

Conclusion

Available in 28-pin SO packages, the new LTC1410 is optimized for many high speed dynamic sampling applications including ADSL, compressed video and dynamic data acquisition.

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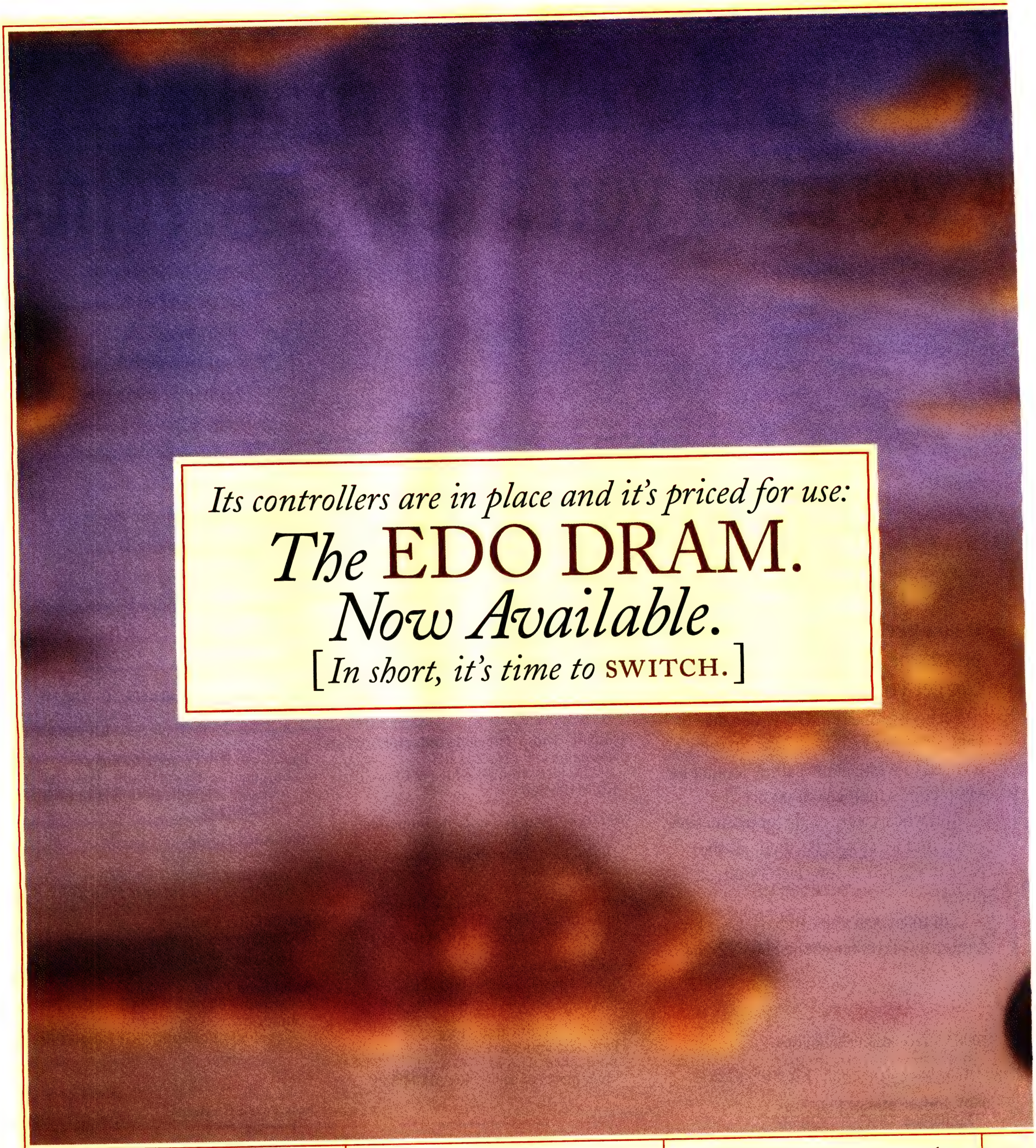

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KM48C2104A	2Mx8	50, 60, 70
KM44C1004C	1Mx4	60, 70, 80
KM416C1004A	1Mx16	60, 70, 80
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CIRCLE NO. 171

Class D amplifiers provide high efficiency for audio systems

JEFFREY D SHERMAN, HARRIS SEMICONDUCTOR

Advances in MOSFET technology and integrated half- and full-bridge predrivers now make class D amplifiers a practical alternative to linear amplifiers in many applications. The biggest benefit compared to more traditional amplifier topologies is high efficiency.

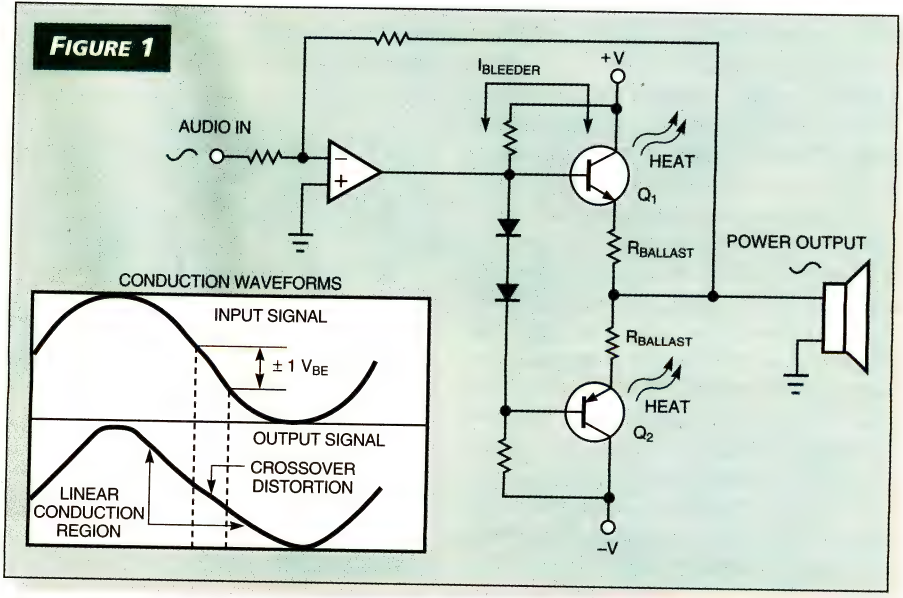
Many engineers are familiar with motor-control circuits that pulse-width-modulate a voltage to control both the direction and speed of a dc motor. You can extend this concept to an audio amplifier by replacing the motor load with a lowpass filter and a speaker and by using an audio input as the control signal. Such amplifiers are class D switching amplifiers, which are analogous to conventional class A, B, AB, and C circuits, in which each switching element is in its linear mode of conduction for a large percentage of each cycle of an audio input signal. This linear operation reduces efficiency to about 60% in the typical class AB amplifier and necessitates the use of large heat sinks.

Alternatively, the switching elements of a class D amplifier are either cut off or in saturation most of the time, allowing high efficiencies. The high efficiency translates into reduced heat sinking, smaller size, and lighter weight. Also, class D amplifiers do not suffer from crossover distortion.

An evaluation-board design shows efficiencies of 94% and THD-plus-noise (THD+N) performance that ranges from less than 1 to 2.8%. Although the THD+N curves for this board's design are not as good as what you can obtain with a high-performance class A or class AB amplifier, the curves are more than adequate in many applications. For instance, automotive manufacturers typically require amplifiers in car stereos to have distortion below 2% at lower power levels and below 5% at peak power. Also, optimizing some of the supporting circuits should result in even higher performance than that of this evaluation board.

The concept of a class D switching amplifier has been around for about 50 years. Early attempts to develop switching amplifiers with vacuum tubes were limited by the tubes' large voltage drops and low current capabilities, which reduced the amplifiers' efficiencies and limited their output power. In the late 1960s, bipo-

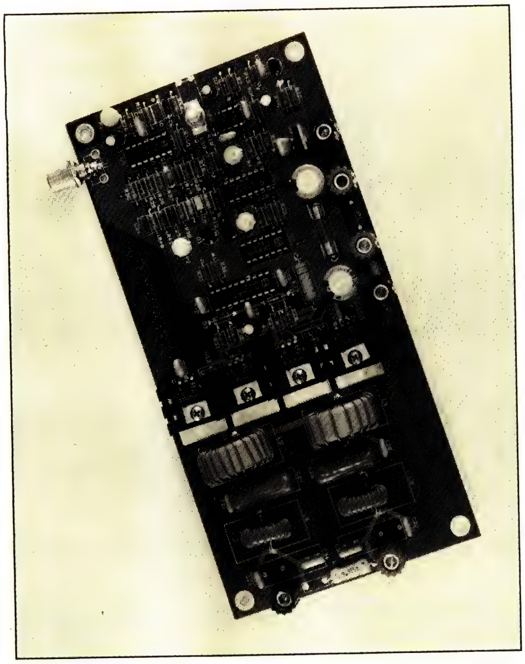
FIGURE 1



Conventional class AB amplifiers never have efficiencies much above 60% because of the losses caused by linear operation, the bleeder circuit, and the ballast resistors.

lar transistors became a practical alternative to vacuum tubes and allowed the implementation of switching amplifiers with very high efficiencies at low frequencies.

However, an audio switching amplifier requires high-frequency operation, which is generally equal to at least four or five times the bandwidth of the 20-kHz audio spectrum. Higher frequency operation makes it easier to design the filter that removes the carrier frequency before the audio signal drives the speaker. Using bipolar transistors at the required frequency of 80 kHz or greater results in excessive switching losses that eliminate the class D amplifier's efficiency advantages.



This evaluation board of the class D amplifier outputs 200W at an efficiency of 94%.

In the 1980s, MOSFETs became available that could meet both the switching-speed and conduction-loss requirements to effectively implement class D amplifiers. The first switching amplifiers using MOSFETs incorporated electrically isolated drivers to allow the use of N-channel devices. N-channel MOSFETs yield more efficient designs; these MOSFETs have approximately one-third the conduction losses of their P-channel counterparts. However, the isolated drive circuits were complex and limited the use of switching amplifiers.

Fabrication processes that allow the integration of high-voltage and logic circuits on one die made possible the first commercially available integrated predrivers for class D amplifiers. For example, the Harris HIP4080 provides monolithic isolation and allows the use of high-side N-channel MOSFETs through the use of a bootstrap circuit and an integrated charge pump. The chip integrates a PWM comparator for modulation. This full-bridge driver can switch MOSFETs at frequencies above 1 MHz, reducing the size of magnetics and simplifying the filter design.

A conventional push-pull (class AB) linear amplifier (**Fig 1**) modulates load power by continuously varying conduction through its pass elements during most, if not all, of the conduction cycle. Q_1 conducts during the positive half-cycle, and Q_2 conducts during the negative. During each half-cycle, the conducting transistor operates in its linear region. The transistor must supply the required current to the load while reducing the voltage between the supply and the load. The power dissipated in the transistor, which equals $(V_{BUS}-V_{LOAD})\times I_{LOAD}$, is wasted in the form of heat. Generally, you must use large heat sinks to prevent the output stage from overheating.

The class AB amplifier uses a bleeder circuit to reduce crossover distortion, which occurs during the zero-crossing of the input signal when neither transistor is on (when the input signal is below the V_{BE} of either transistor). The bleeder circuit biases both transistors on during crossover, but the circuit draws current that further reduces the efficiency of the amplifier.

Ballast resistors in class AB designs prevent the transistors from going into thermal runaway. Bipolar transistors are at risk because their V_{BE}s have negative temperature coefficients. Usually, you must mount the diodes and transistors on the same heat sink to ensure that the V_{BE}s track. The common heat sink helps minimize crossover distortion over temperature.

Class D audio amplifiers

Class D amplifiers convert the audio signal into high-frequency pulses that vary in width with the audio signal's amplitude. The varying-width pulses switch the power-output transistors at a fixed frequency. A lowpass filter converts the pulses back into an amplified audio signal that drives the speakers. This design approach produces an amplifier with better than 90% efficiency and that is more complex than its linear counterpart.

The amplifier requires an integrator, a duty-cycle modulator, a switch predrive circuit, and an output filter. The half-

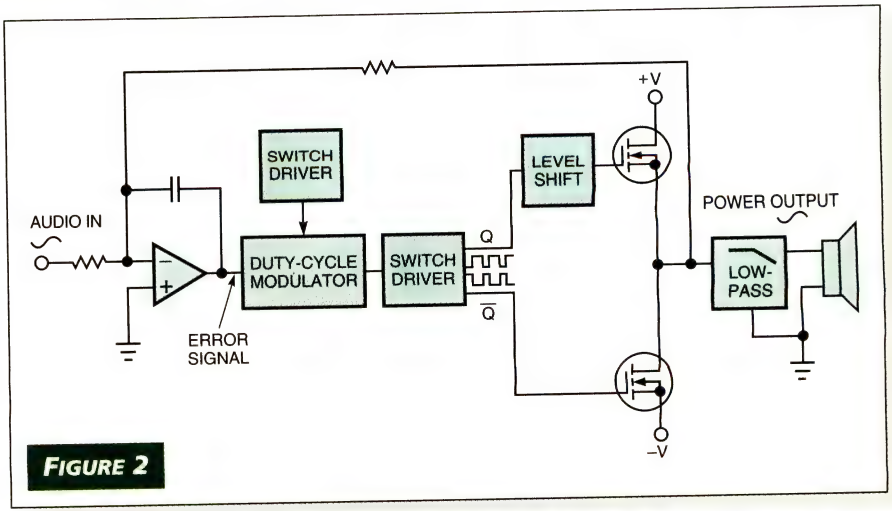
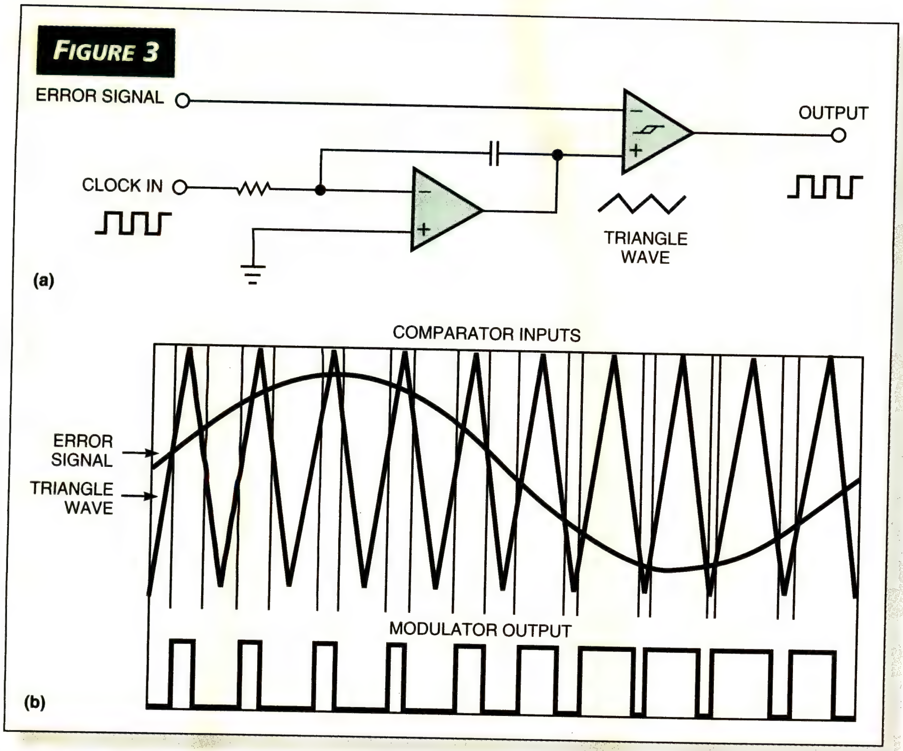


FIGURE 2

In a class D amplifier, the switching elements are either in cutoff or saturation, resulting in lower losses than class AB types. The trade-off is circuit complexity.

FIGURE 3



The duty-cycle modulator compares an error signal to a triangle wave (a). The duty cycle of the modulated output (b) is proportional to the error signal.

bridge class D amplifier using constant-frequency, duty-cycle modulation (**Fig 2**), sums the square-wave output of the switching power transistors with the audio input to provide negative feedback. You cannot take the feedback after the lowpass filter unless you use a complicated compensation network to handle the phase shift that the filter introduces. A two-pole filter, for example, would introduce a 180° phase shift, which would cause the circuit to oscillate.

The square-wave output is synchronous with the audio input, but you must remove the carrier. The integrator sums the two signals and simulates the effect of the output filter. The circuit feeds the resultant error signal into the duty-cycle modulator, which comprises a comparator and a triangle-wave generator (**Fig 3**). Then, the circuit compares the triangle wave to the error signal to produce the modulated output.

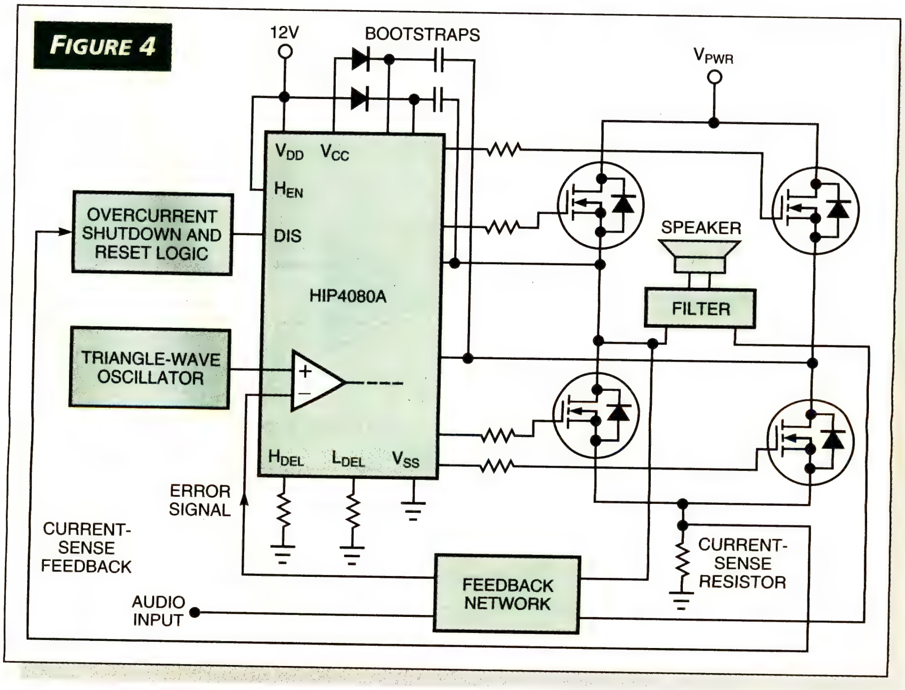
The modulated output is a square wave whose duty cycle is proportional to the input signal. In this half-bridge circuit, this output drives the upper and lower power switches in antiphase; the circuit always drives one switch into saturation while it cuts the other off. The square wave causes the switches to change state as fast as possible, given the technology used to implement the switch. Fast switching limits the time that the switches spend in the linear operating region, thereby increasing efficiency and reducing heat generation. The combination of switching and conduction losses defines the upper bound of the amplifier's efficiency.

The circuit filters out the high-frequency square wave that the power switches generate, leaving only the amplified audio signal. This signal then drives a ground-referenced speaker load.

Fig 4 shows a simplified schematic of a class D audio amplifier using a full-bridge configuration. If you use a full-bridge design, in which the circuit develops a peak-to-peak load voltage equal to twice the supply voltage, you need only a unipolar supply instead of the bipolar supply required for the half-bridge design. The full-bridge circuit operation is similar to that of the half-bridge design, except the full-bridge design uses four MOSFETs instead of two, uses a differential lowpass filter in the feedback network to support the floating load, and requires two lowpass filters to attenuate the carrier.

Four N-channel MOSFETs switch high currents into a low-impedance load. These MOSFETs turn on in pairs, one high-side device with the opposite low-side device. To avoid shoot-

FIGURE 4



This simplified full-bridge class D amplifier uses a monolithic predriver IC.

through, the circuit ensures a dead time between turning off one pair of MOSFETs and turning on the other pair.

MOSFETs in a full bridge need to withstand only half the voltage they would see in a half-bridge circuit. This lower voltage requirement allows you to minimize conduction losses, even though two devices are in the conduction path. Given a fixed die area, two MOSFETs in series have a lower total $R_{DS(ON)}$ than does one MOSFET with twice the drain-source breakdown voltage rating (BV_{DSS}) because $R_{DS(ON)}$ increases nonlinearly with higher drain-to-source breakdown voltage.

Base your MOSFET selection on the following criteria: peak voltage and current requirements, body-diode reverse-recovery time, switching losses, and conduction losses. The peak voltage and current determine the required ratings that the MOSFET must be able to sustain. The body-diode recovery time, switching losses, conduction losses, and output-filter losses determine the output stage's efficiency. You can calculate peak voltage and current using the following equations:

$$V_{PEAK} = \sqrt{2 \bullet P_{OUT} \bullet Z_{LOAD}}$$

and

$$I_{PEAK} = \frac{V_{PEAK}}{Z_{LOAD}}.$$

For example, if you require an output power of 100W into an 8Ω speaker, V_{PEAK} and I_{PEAK} would equal 40V and 5A, respectively. Therefore, the MOSFETs must have a BV_{DSS} above 50V (using a guard band of 25%) and a rated current above 5A.

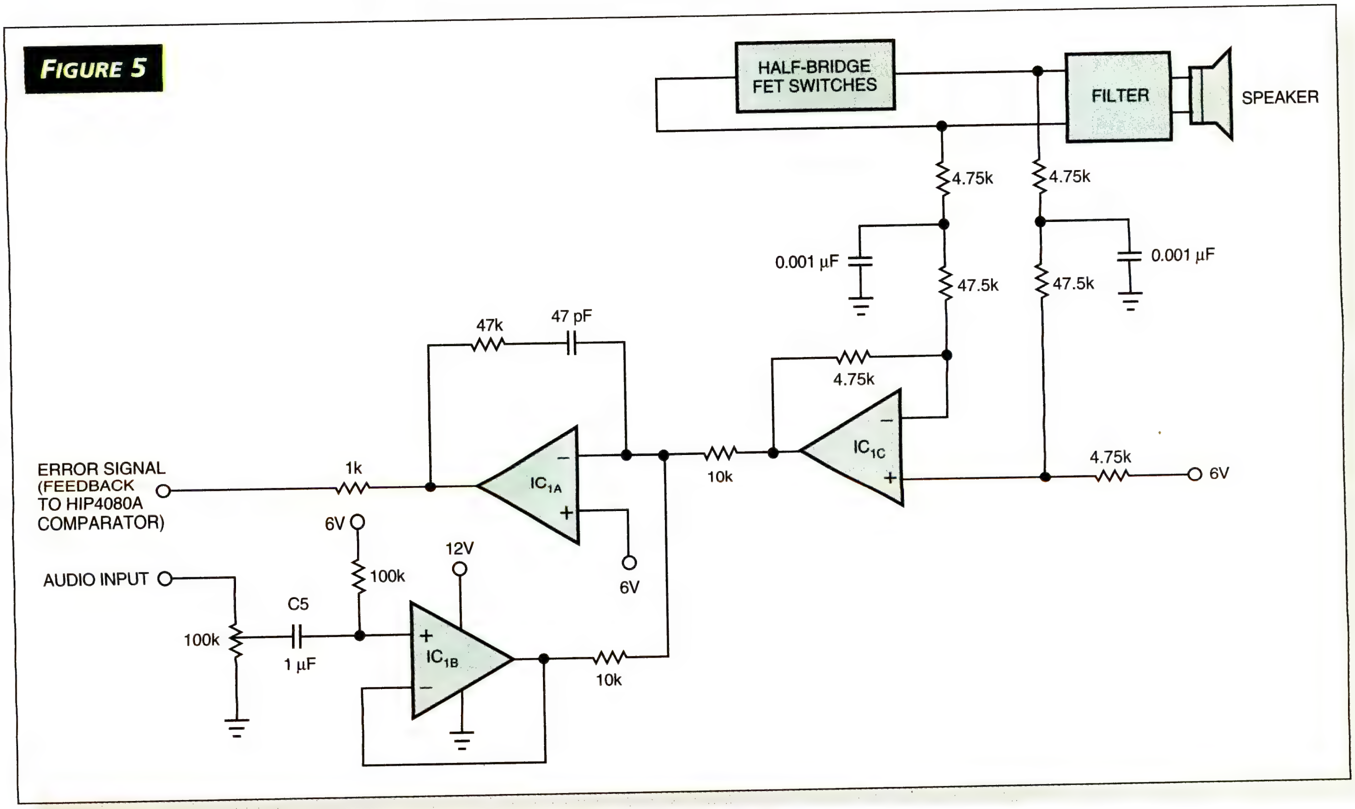
Select a MOSFET with a body diode that has a low reverse-recovery time to reduce the losses that occur when the MOSFETs switch off and on. The current state-of-the-art reverse-recovery time is 100 nsec. You can minimize switching losses by choosing a low switching frequency, a MOSFET with low gate-to-source capacitance, and a driver with high drive capability. In selecting an operating frequency, weigh the advantages of high carrier frequencies against increased switching losses and the increase in radiated EMI/RFI. The lower the switching frequency, the harder it is to filter the carrier from the audio signal.

If you effectively manage these losses, the conduction losses become the dominant factor in the amplifier's efficiency. In other words, choosing a MOSFET with a lower $R_{DS(ON)}$ increases the amplifier's efficiency. For example, a MOSFET with an $R_{DS(ON)}$ of 200 mΩ would reduce the efficiency 5% from ideal. This number results from

$$\Delta\eta = \frac{2 \bullet R_{DS(ON)}}{Z_{LOAD}} = \frac{0.4}{8} = 0.05,$$

multiplying by 2 in the numerator because of the full-bridge topology. However, a lower $R_{DS(ON)}$ of 80 mΩ would reduce the

FIGURE 5



In this feedback network, a differential lowpass filter (IC_{1C} and associated components) attenuates the half-bridge's output by a factor of 11. IC_{1B} ac couples the audio input, and an integrating error amplifier (IC_{1A}) sums the filtered feedback signal and the buffered audio input.

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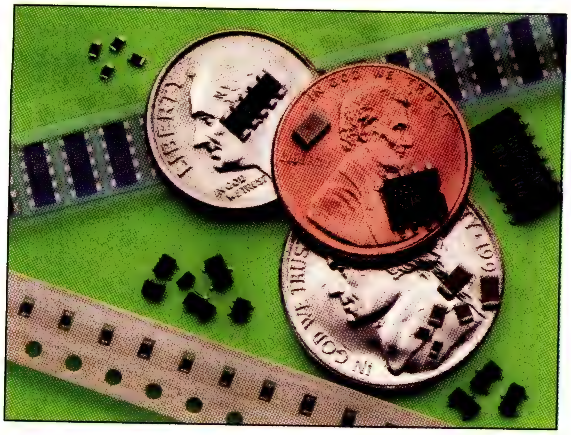

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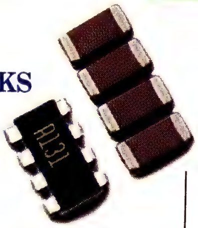

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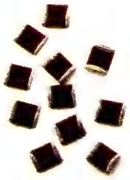

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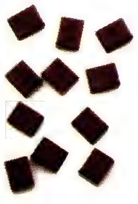

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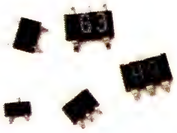

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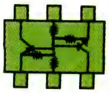

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Fig 5 shows the internal circuitry of **Fig 4**'s feedback-network block. In this circuit, the differential lowpass filter comprising IC_{1C} and associated components attenuates the output of the half-bridge by a factor of 11. Buffer amplifier IC_{1B} ac-couples the audio input. An integrating error amplifier, IC_{1A}, sums the filtered feedback signal and the buffered audio input. The circuit feeds the error signal into the inverting input of the comparator in **Fig 4**'s driver IC, which compares the error signal with a sawtooth waveform to generate the PWM signal. A simple triangle-wave oscillator generates the sawtooth waveform.

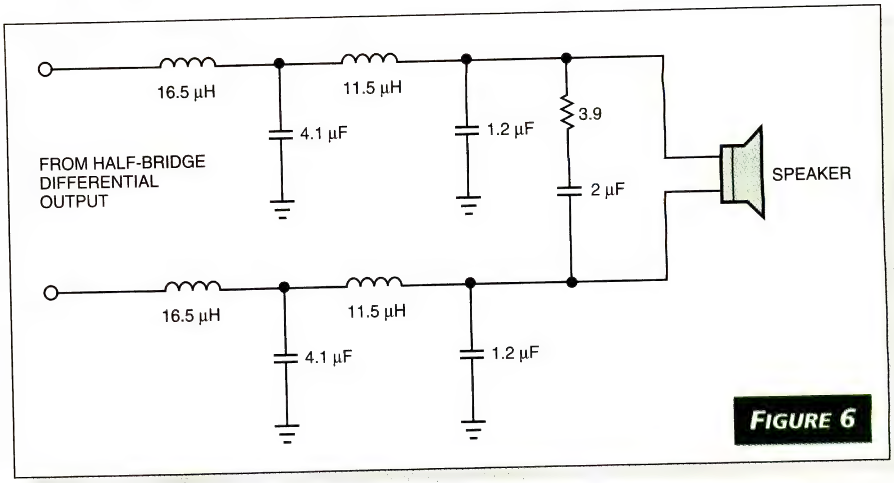


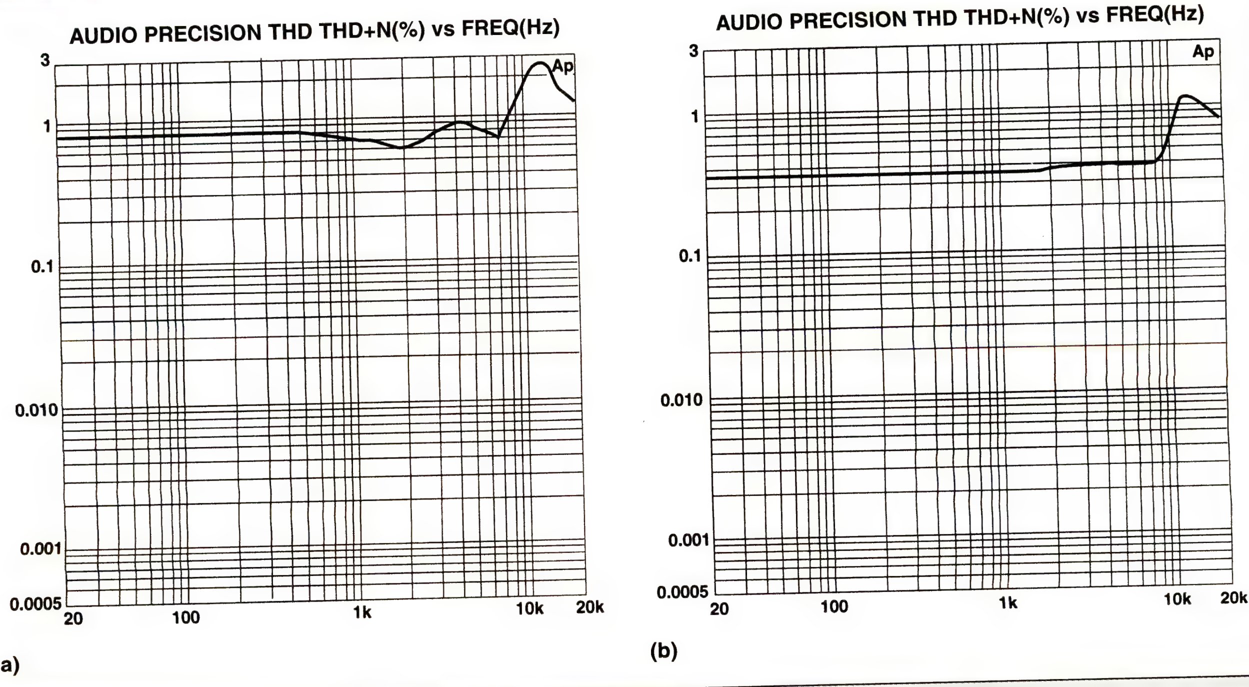
FIGURE 6

A differential, four-pole, lowpass Butterworth filter removes the 250-kHz carrier from the square-wave output and delivers the amplified audio to the speaker.

Another feedback signal in **Fig 4** comes from the current-sense resistor on the ground leg of the half-bridge. The sense resistor should have as low a value as possible to reduce its contribution to conduction losses. Simple circuitry in the overcurrent-shutdown and reset-logic block compares the current-sense output to a voltage reference. If the current rises above the maximum rated current of the MOSFETs, the voltage across the current-sense resistor exceeds the reference, causing a comparator to change state and disable the output drivers. You could also use the current-sense resistor to implement current limiting. This would protect the MOSFETs, but the amplifier's output would distort during an overcurrent condition.

The class D amplifier uses two Butterworth filters (**Fig 6**) to supply the amplified audio signal to the floating load. Butterworth filters provide flat response in the passband, an important criterion in an audio system because a flat response improves dynamic performance. Each filter in

FIGURE 7



When driving 100W to a 4Ω speaker, this evaluation-board design of a class D amplifier produces less than 2.8% THD+N (a). At 10W, THD+N is less than 1.2% (b).

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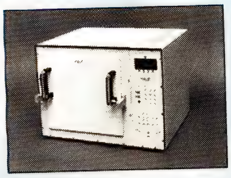

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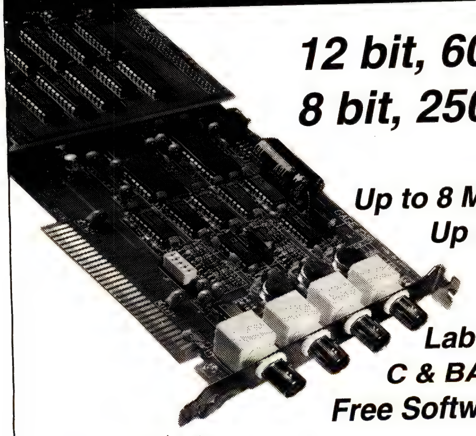

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CIRCLE NO. 46

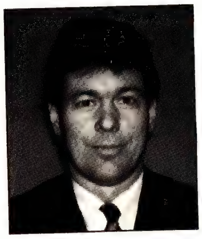
Fig 6 has four poles with 30-kHz cutoff frequencies. The clock rejection of each is 74 dB at 250 kHz, which is the carrier frequency for this evaluation-board circuit. You can improve the rejection by adding poles or lowering the cutoff frequency. An RC filter across the load provides impedance stabilization at high frequencies. Stabilization is necessary because the speaker becomes inductive as frequency increases, and a Butterworth filter requires a resistive load.

When driving 100W into a 4Ω load, this amplifier has a THD+N across the audio spectrum of less than 1% to 8 kHz (**Fig 7a**). Above 8 kHz, THD+N increases to about 2.8% before rolling off. THD increases because the amplifier introduces more nonlinearity as the audio input frequency rises. As the frequency approaches the high end of the audio spectrum (above 12 kHz), THD rolls off because the output filters begin to attenuate the harmonics.

However, distortion at lower power levels—that is, performance at less than peak output—is a better measure of an audio amplifier. An audio amplifier delivers average power that is typically a fraction of its maximum output power, depending on the dynamic nature of the music. At a 10W output level, this class D amplifier's THD+N is less than 1.2% over all the frequencies of interest (**Fig 7b**). THD increases at higher power levels because the amplifier introduces nonlinearities as the output waveform approaches clipping.

THD is primarily a function of filter selection and the feedback network, and you can further reduce distortion to suit the application's requirements. Using a higher grade op amp in the feedback circuit, modifying the compensation network, and improving the linearity of the triangle waveform should all help to improve THD and reduce residual noise. In particular, matching the output filter to the speaker's impedance reduces peaking in the amplifier's closed-loop response and improves the distortion characteristics of the amplifier. EDN

Author's biography



Jeffrey D Sherman is a field applications manager for Harris Semiconductor in Southfield, MI, and is responsible for the staffing and career development of field application engineers in the central United States. He holds a bachelor's degree in electrical engineering from the University of Michigan—Ann Arbor, MI, and a master's in electrical engineering from Northeastern University in Boston.

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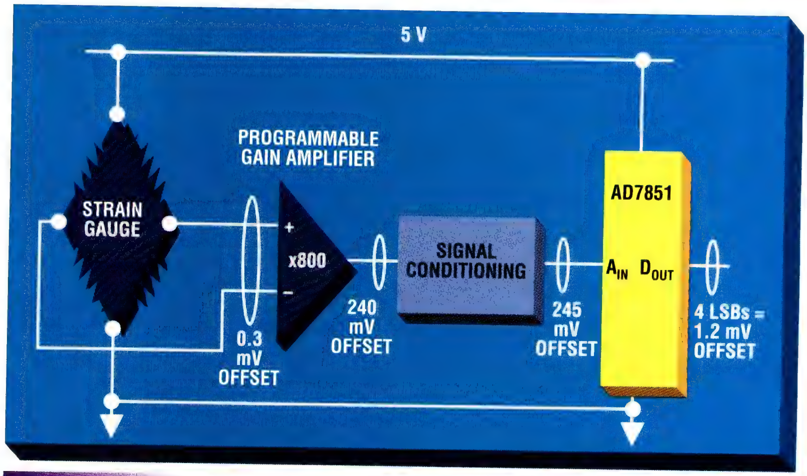
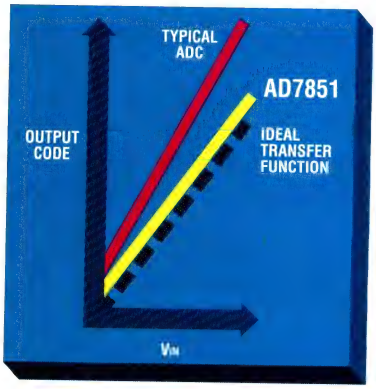


New!

Two Hundred Times Reduction in System Error Using the 14-Bit AD7851

For high-performance industrial and instrumentation applications, choose an inexpensive upgrade path to a 14-bit ADC with the AD7851. Pin-compatible with the even lower-cost 12-bit AD7853, the AD7851 is AC and DC specified at 250 kSPS with a serial output data format. Its system calibration capability facilitates the removal of system offset and gain errors associated with other analog components in the signal path. In a 5 V system, for example, system offset error of the order of 250 mV is reduced to 1.2 mV, equating to a 200 fold reduction.



The AD7851 operates off a single +5 V supply, has reference voltages from +1.2 V to +5 V, an on-chip +4.096 V reference and a power-down mode, and is packaged in tiny 24-pin SSOPs, as well as DIPs and SOICs.

KEY FEATURES
- 250 kHz throughput
- System calibration
- 60 mW power (max.) @ +3.3 V

AD7851 Price $12.00 Faxcode 1873 Circle 01

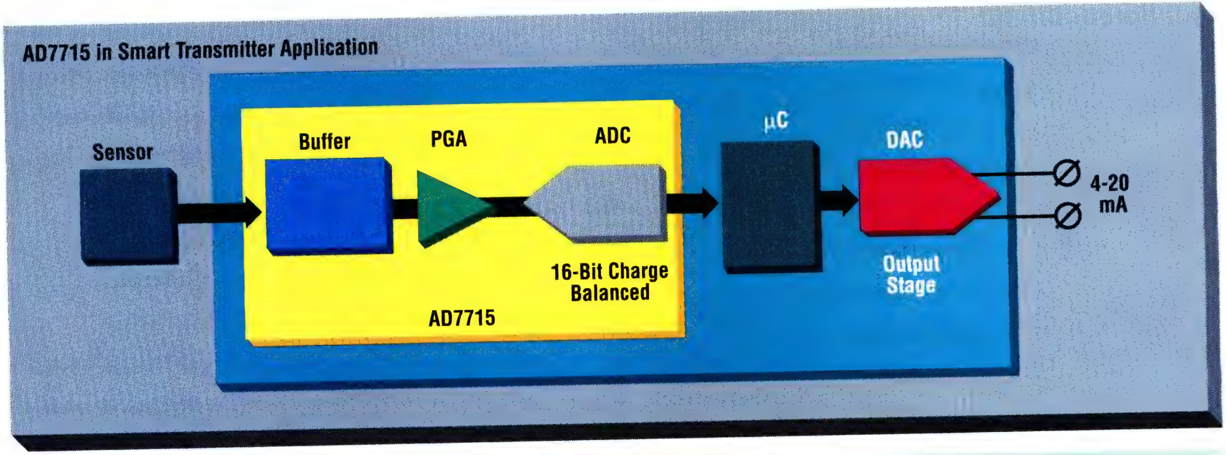
All prices shown in USD, 1000s [illegible] FOB USA

Low-Cost 16-Bit Analog Front-End for Digitizing Low Frequency Signals

At only $6.00 per channel, the AD7715 is targeted for applications such as smart transmitters, and portable or battery-powered equipment used to measure low frequency signals. With up to 16 bits of no-missing codes performance, this A/D converter runs off a single +3 V or +5 V power supply and typically consumes only 1.25 mW. A standby mode drops power to 16 µW typical. With the internal programmable gain amplifier set to X32 or X128, low level signals from a transducer can be applied directly to the single differential input without external preamplification. High level signals can also be accommodated by setting the internal PGA gain to X1 or X2. Available in 16-pin DIP and 16-lead SOIC packages, the AD7715 is specified over the -40° to +85° C temperature range.

KEY FEATURES
- 1.25 mW dissipation @ +3.3 V
- Low cost of only $6.00
- Up to 16 bits of no-missing codes performance

AD7715 Price $6.00 Faxcode 1813 Circle 02


AD7715 in Smart Transmitter Application

10-Bit, 20 MSPS ADC for Less Than $10

Need a high-performance ADC for your low-cost, low-power system? This is THE A/D converter for video, image scanners, digital communications systems and other cost-sensitive applications where low power (just 160 mW at 20 MSPS) is an important feature. This single-supply converter includes a sample-and-hold amplifier, eliminating the need for external buffering. Specified over the 0 to +70° C temperature range, the AD876 is available in a 28-pin SOIC or 48-pin TQFP package. (An 8-bit version is also available in a 28-pin SOIC package.)

KEY FEATURES
- Low cost: 8-bit version only $5.07
- Low power of just 160 mW @ 20 MSPS
- Single +5 V supply

AD876 Price $9.95 Faxcode 1838 Circle 03

High-Speed 16-Bit DAC for Your High Volume Applications

The AD768 delivers the best performance of any high-speed wide-dynamic-range DAC on the market. It's targeted for high-speed applications with its 16-bit resolution and guaranteed 30 MSPS operation. Combine that with guaranteed -74 dB SFDR, and you get a DAC that is ideal for applications such as waveform synthesis, convergence correction for projection TVs and communications. This is a current-out DAC which incorporates a precision +2.5 V reference and draws 500 mW. Operating off a ±5 V supply, the AD768 offers a low glitch energy rating of 35 pV-s.

KEY FEATURES
- Low glitch energy rating of 35 pV-s
- Fast settling time of 25 ns full scale to 0.025%
- On-chip +2.5 V reference

AD768 Price $19.95 Faxcode 1334 Circle 04

High Resolution, High Speed – or Both

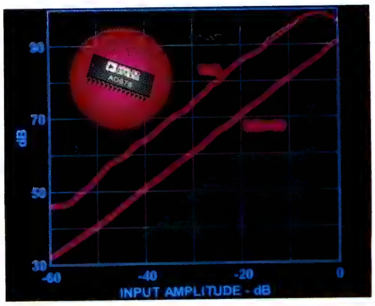
True 16-Bit ADCs at a Low Price (92 dB at 100 kSPS for $25)

High speed (100 kSPS), high resolution (16-bit) and auto-calibration are the reasons why the AD676 and AD677 are the ADCs of choice for data acquisition, instrumentation and general purpose applications. Their 92 dB signal-to-noise ratio, combined with ±1 LSB integral nonlinearity, offer superior 16-bit performance at 100 kSPS throughput rates.

The high accuracy is a result of autocalibration which improves performance without the wasted board space and cost of external trims. A "ground sense" pin is included – invaluable if the signal has to be carried some distance to the A/D converter.

This combination of features makes the AD676 and AD677 the perfect solutions for medical and analytic instrumentation applications. These parts also excel in PC-based data acquisition and industrial applications such as power supply monitoring of transportation and industrial controls.

Both components are fully specified and tested for AC and DC parameters. The AD677 offers easy-to-interface three-wire serial output data, and the AD676 offers full parallel output.



The AD676 is available in a 28-pin ceramic, side-brazed package, as well as a 28-pin plastic DIP. The AD677 is offered in 16-pin skinny ceramic and plastic DIP packages, and 28-pin SOIC packages.

KEY FEATURES
- Low 92 dB SNR @ 100 kSPS throughput
- High 16-bit accuracy and 0.5 LSB RMS noise
- Autocalibration

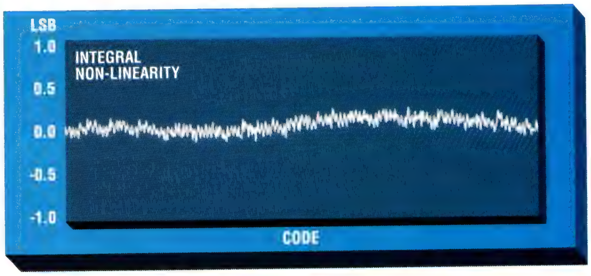
AD676 Price $27.14 Faxcode 1227 Circle 05
AD677 Price $25.08 Faxcode 1228 Circle 06

New!

Industry's First 16-Bit Accurate, Monolithic DAC

Targeted for the ATE, medical and scientific instrumentation, high-end data acquisition and analytical equipment markets, the AD760 is a true 16- or 18-bit self-calibrating DAC with on-board zener voltage reference, double-buffered latches, output amplifier, and serial or byte interface. It provides ±1/2 LSB integral and differential linearity and ±1/4 LSB unipolar offset or bipolar zero. Additionally, it has an on-chip multiplexer to isolate the load from the DAC during self-calibration, and features on-chip power up/down detection which automatically sends the output to 0 V, or another predetermined voltage.

In the serial mode, the AD760 can be operated as either a 16- or 18-bit DAC. It's available in a single SQ grade, and is provided in a 28-pin, 600 mil cerdip package.

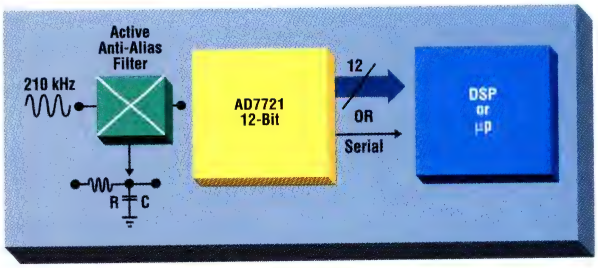


KEY FEATURES
- 16- or 18-bit performance from one package
- ±1/2 LSB INL and DNL, ±1/4 LSB unipolar offset or bipolar zero

AD760 Price $40.00 Faxcode 1827 Circle 07

Fast 12-Bit ΣΔ ADC Eliminates Need for Active Anti-Aliasing Filter

Need to uncomplicate the input anti-aliasing filter design in your system? The AD7721 is a 12-bit ADC with a 150 kHz bandwidth and an output word rate of 312 kSPS which offers all the advantages of digital filter design. In many cases, no filter other than a simple RC rolloff is required with this converter. Other features include a choice of either serial or parallel interfacing, a power-down mode and pseudo-differential inputs. It also offers a calibration mode to minimize offset and gain errors. The AD7721 is available in 28-pin plastic DIP, SOIC and cerdip packages.



KEY FEATURES
- Offers all advantages of digital filter design
- Full power bandwidth of 150 kHz
- Dissipates only 150 mW off single +5 V supply

AD7721* Price $10.00 Faxcode 1829 Circle 08

* Available Fall '95; samples and data sheet available now.

High Resolution, High Speed – or Both

New!

Low-Cost, High-Performance ADC with 3 MSPS

When low cost, high performance and single supply are part of your ADC requirements, the AD1672 is your answer. Complete with an on-board SHA and reference, it uses less than 300 mW of power with a SINAD of more than 68 dB at 250 kHz input. A CMOS-compatible logic for direct interface and a high-impedance analog input are also delivered from this 12-bit converter. If you're designing for communications, imaging or general data acquisition applications, the AD1672 is an outstanding choice.

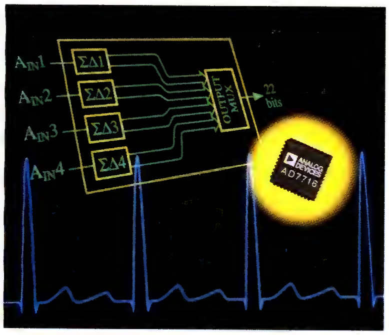
KEY FEATURES
- No missing codes
- Low power of 250 mW
- Excellent bandwidth of 5 MHz

AD1672 Price $29.90 Faxcode 1880 Circle 09

New!

Quad 22-Bit ∑Δ ADC

Designed for medical and bioscience applications (especially patient monitoring systems), the AD7716 contains four independent 22-bit ADCs, each with a programmable dynamic range selectable between 98 dB and 110 dB (for input bandwidths between 36.5 Hz and 584 Hz). The AD7716 is ideal for multi-channel applications where the timing between channels is critical. Housed in a compact, 44-pin surface-mount package and drawing only 50 mW of power, this is the perfect choice when high resolution, integration and low power are required.



KEY FEATURES
- High resolution (98 to 110 dB)
- Full integration of 4 ADCs and decimator on one chip
- Low power of 50 mW total

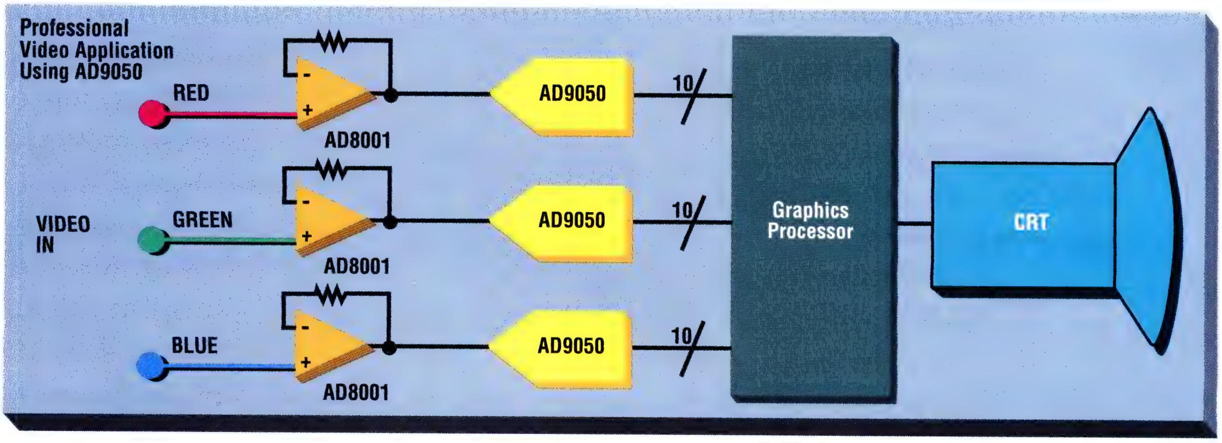
AD7716 Price $29.50 Faxcode 1342 Circle 10

10-Bit, 40 MSPS ADC for Imaging and Video Applications

If you're looking for a low-cost and high-performance 10-bit sampling monolithic ADC for medical imaging or professional video and communications projects, the AD9050 will be the perfect fit. Requiring only a +5 V (300 mW) power and an encode signal to achieve 40 MSPS, this converter provides a guaranteed SNR of more than 53 dB at 10 MHz analog input. Other features include CMOS-compatible (+3 V or +5 V) logic for direct interface, and a high-impedance analog input. Specified to operate over the -40° to +85° C temperature range, it's available in a 28-pin SOIC or SSOP package.

KEY FEATURES
- Built-in reference and track/hold amplifier
- Requires only +5 V and encode signal to achieve 40 MSPS
- Guaranteed SNR of >53 dB @ 10 MHz analog input

AD9050 Price $19.90 Faxcode 1843 Circle 11


Professional Video Application Using AD9050

New!

12-Bit, 600 kSPS ADCs that Survive Overvoltage

Tough data acquisition and control environments with fluctuating line voltages are the prime applications for the AD7892, a 12-bit sampling ADC with a maximum throughput rate of 600 kSPS. AND, at this speed and with excellent AC specs, the AD7892 ("-3" version) is ideal for high-speed telecomm applications such as HDSL. It's a versatile, high-speed ADC designed to dissipate low power (60 mW typical) while providing the flexibility of both serial and parallel interface capability. Resilient enough to protect from overvoltage fault conditions (up to ±17 V for the "-1" version), the AD7892 features an on-chip reference, as well as a power-down mode. Available in 24-pin plastic DIP, SOIC and cerdip packages, it operates within the -40° to +85° C temperature range.

KEY FEATURES
- Maximum overvoltage fault protection to ±17 V
- Low power dissipation of only 60 mW
- Serial and parallel interface capability

AD7892 Price $12.75 Faxcode 1384 Circle 12

New!

Rail-to-Rail Quad 10-Bit DACs Operate from +3 V and +5 V Supply

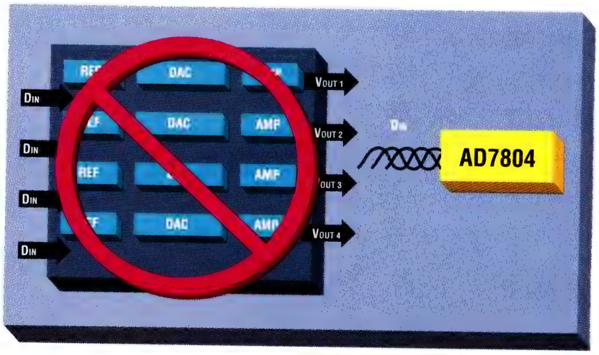
The serial interface AD7804 and parallel interface AD7805 are the world's first quad 10-bit digital-to-analog converters where the output voltage can swing rail-to-rail with a single supply. Control over individual channels is available by means of a channel register. This allows individual power down of each DAC, allows individual selection of the reference input and individual DAC clear functions. A system register allows the user to power down all DACs, clear all DACs and select the coding system.

The DACs provide output voltage signals in the form of Vbias ±Vswing. The complete transfer function of each DAC can be shifted around the Vbias point using an on-chip sub-DAC. All DACs contain double-buffered data inputs which allow all analog outputs to be simultaneously updated using the asynchronous LDAC input.

Power consumption is less than 8 mW per DAC in normal operation and goes to less than 2 µW per DAC in the power-save mode. Maximum settling time to 8 bits is 1 µs, and to 10 bits is 4 µs. The AD7804 is available in a 16-pin DIP or SOIC package, and the AD7805 is offered in a 28-pin DIP or SSOP package.

KEY FEATURES
- Output voltage swings rail-to-rail with single supply
- Less than 8 mW per DAC power usage
- Operation from +3 V and +5 V

AD7804 Price $5.65 Faxcode 1830 Circle 13
AD7805 Price $6.35 Faxcode 1884 Circle 14



8-Channel 12-Bit 500 kSPS Data Acquisition System on One Chip

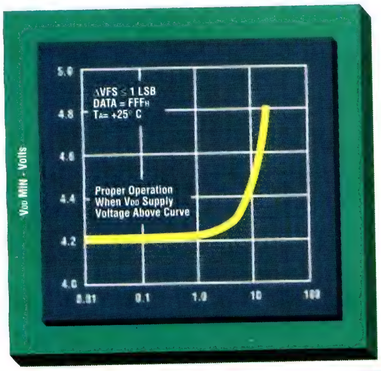
With analog input ranges up to ±10 V, this high-speed DAS, including an 8-channel mux, reference, S/H and clock, provides a per channel conversion time better than 2.0 µs. And, with a choice of a parallel or serial interface, throughput rates are 500 kSPS and 300 kSPS, respectively. In addition to the ±10 V input range, the AD7891 accepts ±5 V, ±2.5 V, and +5 V and +2.5 V. Operating from a single +5 V supply, power dissipation is only 60 mW in normal operation, falling to 75 µW in standby mode. This system is packaged in a space-saving 44-pin PQFP and PLCC.

KEY FEATURES
- 8 input channels with ±10 V input range
- 500 kSPS throughput
- Parallel or serial output data format

AD7891 Price $15.30 Faxcode 1383 Circle 15

Single-Supply, Dual 12-Bit DACs Provide Total System

The AD8522 and AD8582 are dual 12-bit single-supply DACs that offer a complete solution for your portable and battery-operated equipment applications. Each part includes a reference, rail-to-rail amplifiers and latches – AND uses only 5 mW of power. Full-scale voltage of +4.095 V with 1 mW/bit output coding creates a programming-friendly environment while maximizing the analog voltage output swings for all loads. The AD8522 has a serial digital interface and is available in 14-pin DIP and SOIC packages, while the AD8582 has a parallel interface and is available in 24-pin DIP and SOIC packages.

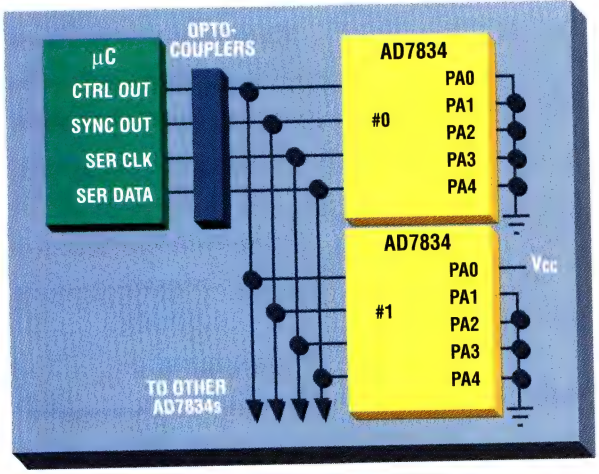


KEY FEATURES
- World's smallest dual 12-bit DACs
- Need only +5 V supply
- Low 5 mW power consumption

AD8522	Price $7.86	Faxcode 1427	Circle 16
AD8582	Price $9.44	Faxcode 1428	Circle 17

Quad 14-Bit DACs CLEAR to User-Defined Voltage

The AD7834 (serial) and AD7835 (parallel) quad 14-bit DACs automatically control the DAC output levels to a user-defined voltage on the "device signal ground" pin during power up/down. In addition, a CLR pin can, at any time, be used to set all signal outputs to this same voltage. These features provide advantages in many control applications, particularly during power on/off sequences. Both parts are particularly suitable as level-setting DACs in ATE applications because of an output range that is variable up to a max. of ±8.192 V.



The AD7834's serial interface facilitates opto-isolation while its multi-package addressing (up to 32 packages or 128 channels) provides for an efficient "daisychaining" arrangement in high channel-count applications. Other features include double-buffered input latches, 14-bit monotonicity and negligible DC crosstalk. The serial version (AD7834) is packaged in 28-pin DIP and SO, while the parallel version (AD7835) is in 44-pin PQFP and PLCC.

KEY FEATURES
- Double-buffered input provides simultaneous update of all 4 DACs
- CLEAR function to user-defined voltage
- Variable voltage output to max. of ±8.192 V

AD7834	Price $21.25	Faxcode 1859	Circle 18
AD7835*	Price $23.00	Faxcode 1860	Circle 19

* Available Fall '95; samples and data sheet available now.

Fast Quad 12-Bit DAC Costs $3/Channel

The quad AD7564 is a 12-bit current-output DAC with independent reference inputs. Operating from a single +5 V supply voltage in normal mode, and +3.3 V to +5 V in biased mode, this DAC features a fast serial interface for three-wire data loading with a 100 ns clock cycle time. Its low power dissipation (<10 μW) makes it an ideal choice for use in low-power, portable and battery-operated equipment. The double-buffered latches allow this DAC to be individually addressed and simultaneously cleared or updated using asynchronous inputs, making it a perfect device for high pin-count ATE applications, too.

The AD7564 offers 0.5 LSB INL, 500 ns voltage settling with an AD843 op amp, and a low (40 mV-s) glitch impulse. It's housed in 28-pin SOIC, SSOP or DIP packages, and is rated for -40° to +85° C operation.

KEY FEATURES
- Low cost of $3/channel
- Low power dissipation of <10 μW
- Operates from single +5 V or +3.3 V to +5 V supply

AD7564	Price $ 11.90	Faxcode 1313	Circle 20

New!

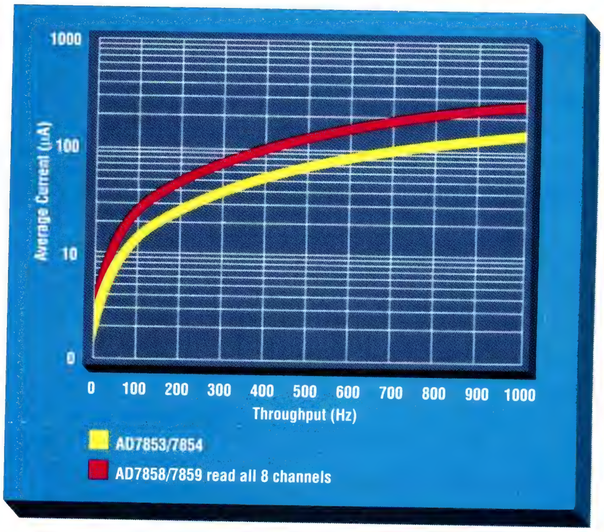
Battery-Compatible 12-Bit ADCs Eliminate System Errors

When portability and performance at a competitive price are your design requirements, the ONLY choice for your 12-bit ADC is one of the AD785x Series. With throughput rates up to 200 kSPS (100 kSPS for "L" grade) and power-save modes that reduce power consumption to less than 40 μW at low sample rates, these ADCs are the perfect choice for battery-powered and low-power applications, ranging from portable personal computers to instrumentation and control systems. Their small SSOP and PQFP packaging is an additional benefit when selecting these parts.

Both the single (AD7853/4) and 8-channel (AD7858/9) models have two input voltage ranges: 0 to Vref and -Vref/2 to +Vref/2. Input signal range is to the supply of +3.3 V or +5 V, and the parts are capable of converting full power signals to 100 kHz. The serial AD7853/8 can accommodate 3-wire SPI or 2-wire 8051 compatible connections. The AD7854/9 offer a parallel and byte I/O port.

The AD785x series features a calibration mode to null system offset and gain errors associated with external signal conditioning circuitry. They are fully specified for AC and DC applications; INL is ≤1 LSB and SNR is 70 dB.

AD7853	Price $ 8.95	Faxcode 1814	Circle 21
AD7854	Price $10.00	Faxcode 1874	Circle 22
AD7858	Price $ 9.95	Faxcode 1815	Circle 23
AD7859	Price $11.75	Faxcode 1879	Circle 24



AD785x Family Selection Guide

	Part	Input Channels	Power @ 3.3 V (mW max)	Output Format	Smallest Package
	AD7853	1	16.5	Serial	24-SSOP
NEW	AD7854	1	16.5	Parallel	28-SSOP
	AD7858	8	16.9	Serial	24-SSOP
NEW	AD7859	8	16.9	Parallel	44-PQFP

12-Bit ADCs in 8-Pin SOIC Feature *Automatic Power-Down* and ±10 V Input Range

For small footprint 12-bit ADCs, you need look no further than the AD7896 and AD7893 to fill your needs. Both converters pack a fast 6-μs ADC (8 μs for AD7896), track-and-hold amplifier, control logic and a high-speed serial interface, all in 8-pin SOIC or DIP packaging.

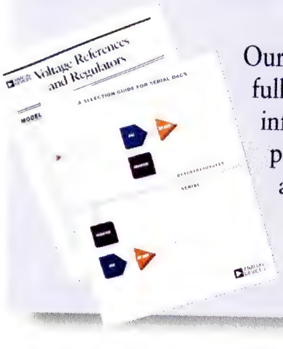
The AD7893, running off a single +5 V supply, accepts input ranges up to ±10 V. The AD7896, specified from +2.7 V to +5.5 V, features a proprietary *automatic power-down mode* invoked between conversion cycles, making it an efficient solution for battery-powered or portable applications. Power dissipation is 15 mW at full speed, and only 36 μW in power-down mode. The AD7896 accepts an analog input range of 0 V to the supply.

KEY FEATURES

- Automatic power-down mode (AD7896)
- Up to ±10 V input from +5 V supply (AD7893)
- 8-pin SOIC or DIP package

AD7896	Price $6.75	Faxcode 1816	Circle 25
AD7893	Price $9.00	Faxcode 1385	Circle 26

New Selection Guides for Serial DACs, Voltage References/Regulators



Voltage References and Regulators
A SELECTION GUIDE FOR SERIAL DACS

Our new 12-page selection guide is just what you need to review the specifications of our full line of single, dual, quad and octal serial DACs. Additionally, we've prepared an informative guide containing specifications and selection criteria for over 25 of our most popular voltage references and regulators. To get your FREE copies, simply complete and return the enclosed reply card.

Serial DAC Guide	Circle 27
Voltage Reference/Regulator Guide	Circle 28

Low-Cost, Low-Power, Low-Profile Solutions

New!

8-Channel TrimDACs® Offer Low Cost and Power Savings

Low-cost, eight-channel potentiometer divider TrimDACs® are now available for applications such as automatic adjustments, trimmer replacements, vertical deflection amplitude adjustments and voltage controlled gain and offset adjustments. The AD8801 has a preset midscale, and the AD8803 provides independent control of both the top and bottom end of the potentiometer divider. Both models consume only 30 µW from +5 V power supplies. In the power-shutdown mode, no current is consumed by the potentiometer divider, resulting in a 5 µA sleep state. Parts are available in 16-pin plastic DIP and the 1.5mm high SO-16 surface mount packages.

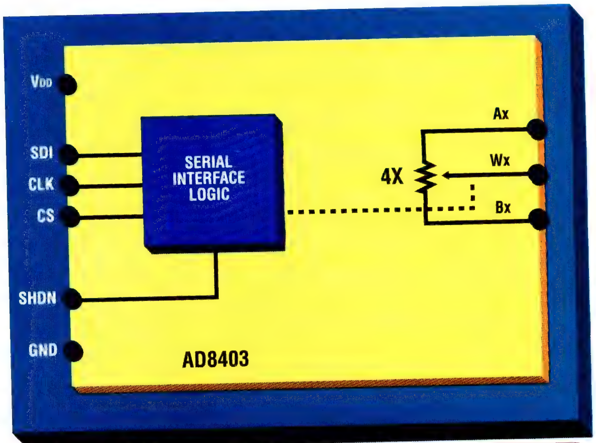
KEY FEATURES
- 5 µA power-shutdown sleep state
- Compact 8 channels in SO-16 package
- Restores previous wiper setting after shutdown

AD8801	Price $3.49	Faxcode 1876	Circle 29
AD8803	Price $3.49	Faxcode 1878	Circle 30

New!

8-Channel RDACs Provide Solid-State Control

Want to replace your mechanical potentiometers with more precise and accurate devices? Then try our solid-state dual- (AD8402) and quad- (AD8403) channel 8-bit RDACs (Resistor Digital-to-Analog Converters). They are a set of 256 position, digitally-controlled variable resistors which operate from +2.7 V to +5.5 V in single-supply systems with rail-to-rail signal range. These RDACs can be used as programmable filters, delays or time constants, volume controls, DC gain/offset adjustments and line impedance matching components.



KEY FEATURES
- Digitally controlled resistance
- Mid-scale reset
- Power shutdown <5 µA

AD8402	Price $1.66	Faxcode 1867	Circle 31
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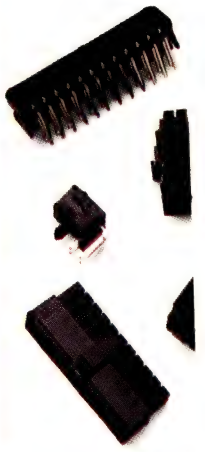

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CIRCLE NO. 215

Understanding a relay's operation can prevent trouble down the line

DOUG LIONETTI, AROMAT CORP

The venerable relay has undergone some changes in the past few years. Designers have supplemented conventional SSRs with optically coupled SSRs, challenging the familiar EMRs. You should understand the operation of these SSRs to get the best performance results.

The term "relay" generally designates a device that provides an electrical connection between two or more points in response to a control signal. The most common type, the electromechanical relay (EMR), has been around for over 100 years. During the past several decades, solid-state relays (SSRs), such as silicon-controlled rectifiers (SCRs), emerged. In the last few years, the optically coupled MOSFET, the PhotoMOS relay, has become available. The PhotoMOS relays have LED inputs and MOSFET outputs that provide input-to-output isolation that compares with the isolation obtainable from EMRs. **Table 1** compares the major functional characteristics of the relays.

PhotoMOS relays appear to beat SSRs and EMRs (**Table 1**). However, SSRs and EMRs continue to prevail in certain cases, such as heavy loads. PhotoMOS devices capable of handling loads in excess of 1A became available in 1993. Currently, PhotoMOS devices that have the highest capacity can switch as much as 4A at 60V dc. For lower currents, you should consider PhotoMOS relays for every relay application.

Over the years, relay manufacturers have developed a terminology and data-sheet format that you should understand before selecting a relay. However, relay terminology, particularly relay ratings, is not easily understood. **Fig 1** shows a specifications summary of a typical data sheet for Aromat's ultraslim polarized relay, the TN-relay. SSR and PhotoMOS specification sheets differ slightly from EMR specification sheets, and some of the confusion comes from the EMR specifications. The EMR specifications fall into two broad categories—contact and coil characteristics. Although the complete specification may take three to four pages, a summary is sufficient to make a preliminary decision as to whether a particular relay fits the application.

If you have read the "Definition of Relay Terminology" in Aromat's data book, you are familiar with the statement "arrangement is 2 form C." The confusion can come from

TABLE 1—RELAY-SPECIFICATION COMPARISON

Parameters	PhotoMOS	EMR	SSR
High reliability*	X		X
Infinite life*	X		X
Fast operation	X		X
100% contact stability*	X		X
Quiet—no audible noise	X		X
No EMI	X		X
Insensitive to magnetic fields*	X		X
Small size/high density*	X		X
Any-position mounting**	X		X
High I/O isolation* (1500V and up)	X	X	
Switches low analog/digital signals	X	X	
No zero crossover problem	X	X	
Surface mounting in the SO package	X		
Parallel operation	X		
Controlled rise and fall times	X***		
Switching currents about 4A		X	X

* Especially important in PhotoMOS versus reed-switch applications
** CRUCIAL versus mercury-wetted units
*** Developed in 1994

the initial-contact resistance, which is the maximum contact resistance of a new relay before you take it out of the box and place it into a circuit. The initial-contact resistance is commonly measured by passing a certain current through the contacts and noting the resultant voltage drop. For the case in **Fig 1**, the initial-contact resistance is 1A×0.06ω=0.06V dc.

Fig 2a better explains this concept. The initial (out-of-the-box) resistance is somewhat greater than after about 100,000 operations. This decrease in resistance occurs because the relays hit one another as they close, causing the contact surface to become smooth. The smoother surface lowers the initial resistance. This action is particularly prevalent in relays with gold-plated contacts.

As the contacts begin to wear, and if they are not properly protected, they show signs of arcing damage, and the contact resistance begins to increase gradually. You have to decide how much contact resistance the application can tolerate before you have to replace the relay. In SSRs and PhotoMOS relays, the contact resistance, or on-resistance, remains stable throughout the life of the relay.

The next important consideration is the relay's contact material. **Table 2** presents characteristics of some common contact materials. Even with the aids in **Table 2**, you may still be confused as to the meanings of terms such as cladding, plating, and flash plating. Cladding results in a gold layer of more than 5 microns thick. Plating implies a gold-layer plating of more than 2 microns and less than 5 microns. Flash plating means that the gold layer is less than 2 microns. Obviously, in the case of SSRs and PhotoMOS relays, there is no such concept as contact material.

FIGURE 1

SPECIFICATIONS

Contact

Arrangement			2 Form C
Initial contact resistance, max. (By voltage drop 6V DC 1A)			60mΩ
Contact material			Gold-clad silver
Rating (resistive load)	Max. switching power		30W, 62.5VA
	Max. switching voltage		110V DC, 125V AC
	Max. switching current		1A
	Min. switching capability		10μA, 10mV DC
UL/CSA rating			1A 30V DC 0.5A 125V AC 0.3A 110V DC
Expected life (min. operations)	Mechanical (at 180cpm)		10^8
	Electrical (at 20cpm)	1A 30V DC resistive	2×10^5
		0.5A 125V AC resistive	10^5

Characteristics

Max. operating speed (at rated load)		20cpm
Operate time* (at nominal voltage)		Max. 3msec. (Approx. 2msec.)
Release time* (at nominal voltage)		Max. 3msec. (Approx. 1msec.)
Set time* (latching) (at nominal voltage)		Max. 3msec. (Approx. 2msec.)
Reset time* (latching) (at nominal voltage)		Max. 3msec. (Approx. 2msec.)
Initial breakdown voltage	Between open contacts	750Vrms for 1 min.
	Between contact sets	1,000Vrms for 1 min.
	Between contact and coil	1,000Vrms for 1 min.
FCC surge voltage between open contacts		1,500V
Initial insulation resistance		Min. 1,000MΩ (at 500V DC)
Temperature rise (at nominal voltage)		Max. 50°C
Ambient temperature		−40°C to +70°C −40°F to +158°F
Shock resistance	Functional	Min. 490m/s^2 (50G)
	Destructive	Min. 980m/s^2 (100G)
Vibration resistance	Functional	176.4m/s^2 (18G), 10 to 55Hz at double amplitude of 3mm
	Destructive	294m/s^2 (30G), 10 to 55Hz at double amplitude of 5mm
Unit weight		Approx. 1.5g .053 oz.

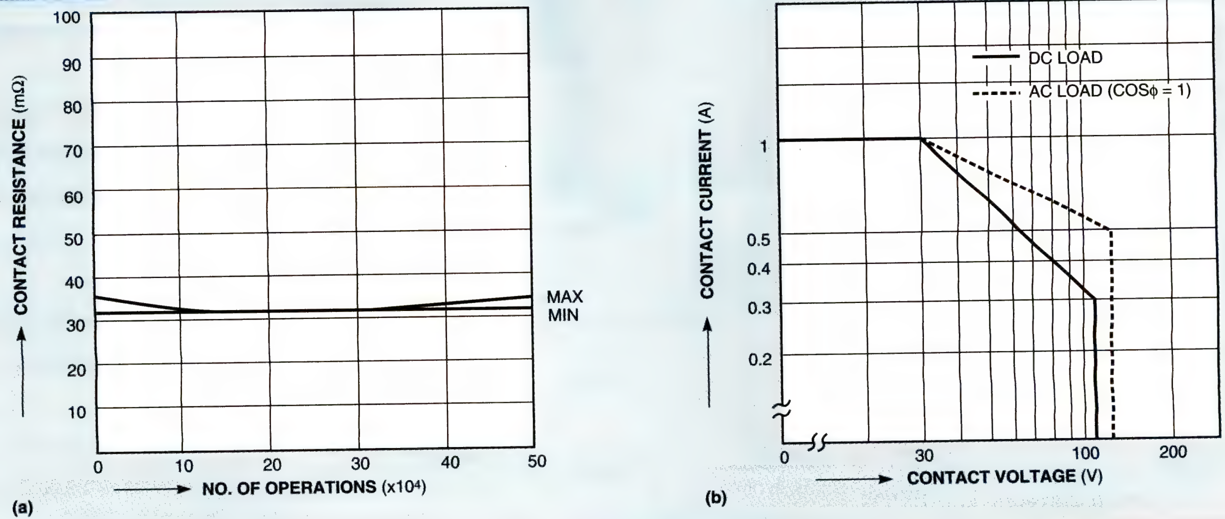
*Excluding contact bounce time

In this typical specification data sheet for an Aromat TN-relay, the specification falls into contact and characteristic categories.

The limitations of power-switching curves

The switching capabilities of a relay raise questions because switched power does not relate to the switched cur-

FIGURE 2



The contact resistance of an EMR is slightly higher when taken out of the box and at long life, due to wear (a). The maximum switching-power rating for an EMR follows two curves, dc and ac, that don't conform to Ohm's law (b).

rents and voltages in accordance with Ohm's law. For example, a TN relay can switch 30W. You may wonder if you can switch 2A at 12V dc because it is less than 30W. Electromechanical devices have separate maximum ratings for power, current, and voltage that are not related to Ohm's law. You should consult the maximum switching-power curve as a function of current and voltage to determine the safe switching-power limits for a given relay. **Fig 2b** depicts such empirically derived curves for the TN relay, a dc curve, and an ac curve. The maximum current limitation for dc and ac curves means the relay can switch this current at any voltage ranging up to 30V, where the current meets the device's 30W power limit. The current then dips to stay within the power limit as the voltage increases up to as the voltage limit of 110V dc. For safe operation, you must stay under the curves.

Relay-life expectancy is specified as mechanical, such as a relay turned on and off without any electrical load on the contacts, or electrical, either ac or dc. The mechanical-life expectancy is easier to comprehend than the electrical-life expectancy because of the test conditions under which the electrical life is determined. Because you can't test a relay under every kind of loading, such as inductive, motor, capacitive, lamp, etc, you perform most electrical-life tests with a pure resistive load. A load that remains unchanged throughout the test is a wire-wound resistor. You must determine life expectations under any conditions other than resistive on a case-by-case basis. However, you can obtain certain data for some loads from the relay manufacturer.

The operate-time specification is also ambiguous. Aromat specifies it as the approximate value in msec. The reason for the ambiguity is bounce. It is well known that every EMR has some bounce before a solid continuous contact is made. Aromat specifies the operate time from the instant the device is energized to the instant the first contact is made, without including the bounce. In PhotoMOS relays, the operate time is well-defined because there is no bounce.

A relay with an operate-time specification of 30 msec is within many customer's needs. In most commercial, in-dustrial, and consumer applications, the operate time is seldom an issue. However, if the operate time becomes an issue, and a relay must operate much faster, discussions with an application engineer become necessary. If you really need and can pay for an accurate operate time, you can ask the vendor to select for shipment only units that meet a minimum operate-time specification.

Ambiguous specifications

Breakdown, temperature, and shock specifications are also ambiguous at times. For example, some users misinterpret the breakdown specification as equivalent to a surge. **Fig 1** gives the surge specification as between open contacts only, and the surge specification is twice the rms breakdown voltage. Surges are generally short (measured in μsec) and have considerably faster rise and decay times (dv/dt). A breakdown

TABLE 2—CHARACTERISTICS OF COMMON CONTACT MATERIALS

	Material	Characteristics
Contact material	Ag (silver)	Electrical and thermal conductivity are the highest of all metals, exhibits low contact resistance, is inexpensive and widely used. One disadvantage is that it easily develops a sulfide film in a sulfide atmosphere. Care is required at low voltage and current levels.
	AgCd (silver cadmium)	Exhibits the conductivity and low contact resistance of silver as well as excellent resistance to welding. Like silver, it easily develops a sulfide film in a sulfide atmosphere.
	AgW (silver tungsten)	Hardness and melting point are high, arc resistance is excellent, and it is highly resistant to material transfer. High contact pressure is required. Contact resistance is relatively high, and resistance to corrosion is poor. Also, there are constraints on processing and mounting to contact springs.
	AgNi (silver nickel)	Equals the electrical conductivity of silver, excellent arc resistance.
	AgPd (silver palladium)	At standard temperature, good corrosion resistance and sulfidation resistance. However, in dry circuits, organic gases adhere, and it easily develops a polymer. Gold clad is used to prevent polymer buildup; expensive.
	PGS alloy (platinum, gold, silver)	Excellent corrosion resistance, used mainly for low-current circuits. (Au:Ag:Pt=69:25:6.)
Surface finish	Rh plating (rhodium)	Combines perfect corrosion resistance and hardness. As plated contacts, used for relatively light loads. In an organic-gas atmosphere, care is required as polymers may develop. Therefore, it is used in hermetically sealed relays, such as reed relays; expensive.
	Au clad (gold clad)	With its excellent corrosion resistance, Au is pressure welded onto a base metal. Special characteristics are uniform thickness and the nonexistence of pinholes; especially effective for low-level loads under relatively adverse atmospheres; often difficult to implement clad contacts in existing relays.
	Au plating (gold plating)	Similar effect to Au cladding; depending on the plating process used, supervision is important because of the possibility of pinholes and cracks. Relatively easy to implement gold plating in existing relays.
	Au flash plating (gold thin-film plating)	Purpose is to protect the contact base metal during storage of the switch or device with built-in switch. However, a certain degree of contact stability can be obtained even when switching loads.

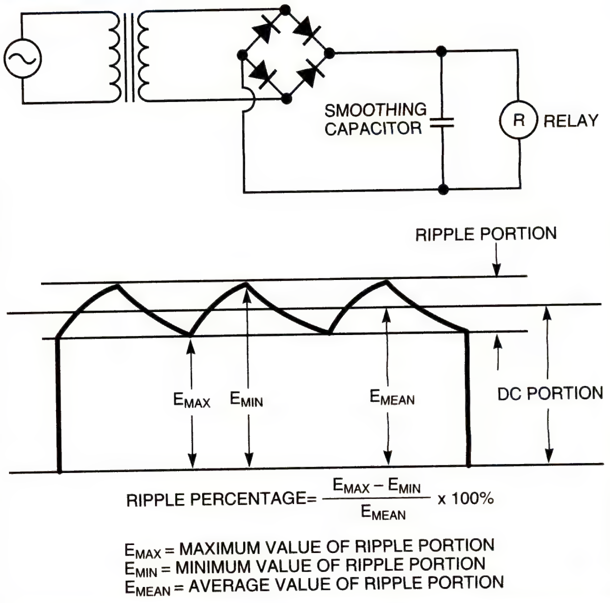
voltage, in contrast, is the maximum rms voltage that a relay can withstand for some prolonged time, such as one minute.

You should use ambient temperature and temperature-rise specifications as a guide to proper relay operation. The dc coil resistance is proportional to its temperature. As the temperature of the copper coil rises, its resistance increases, causing a reduction in current (assuming the applied voltage remains the same). The pickup voltage necessary to turn the relay on increases, depending on the resistance change. Because the electromagnetic force that controls the armature movement is a function of the coil-ampere turns, the coil current determines the point at which the armature moves. To produce the equivalent current at higher coil resistance requires a higher voltage to be applied to the coil. You can calculate the pickup voltage using 0.4% rise in resistance for each degree Celsius of temperature increase.

You can define shock resistance as either functional or destructive. The functional shock means that exposing the relay to a 50g shock causes the contacts to open for 10 µsec or less. In other words, the relay essentially continues to function. The destructive shock means that exposing the relay to a 100g shock could cause the relay to become inoperative due to breakage, bending, or other physical damage to its operating mechanism. At shock values between functional and destructive, the relay contacts open for more than 10 µsec but subsequently close, and the relay continues to operate.

The same terminology applies to the vibration resistance. The correct way to specify the vibration resistance is to give the vibration-frequency range and the amplitude. The specification is incomplete without the amplitude.

FIGURE 3


SMOOTHING
CAPACITOR
R
RELAY
RIPPLE PORTION
E_MAX
E_MIN
E_MEAN
DC PORTION
RIPPLE PERCENTAGE= (E_MAX – E_MIN) / E_MEAN x 100%
E_MAX = MAXIMUM VALUE OF RIPPLE PORTION
E_MIN = MINIMUM VALUE OF RIPPLE PORTION
E_MEAN = AVERAGE VALUE OF RIPPLE PORTION

This simple full-wave rectifier is an adequate power supply for driving an EMR coil, provided the ripple voltage is less than 5%.

Relay coil needs a quality power source

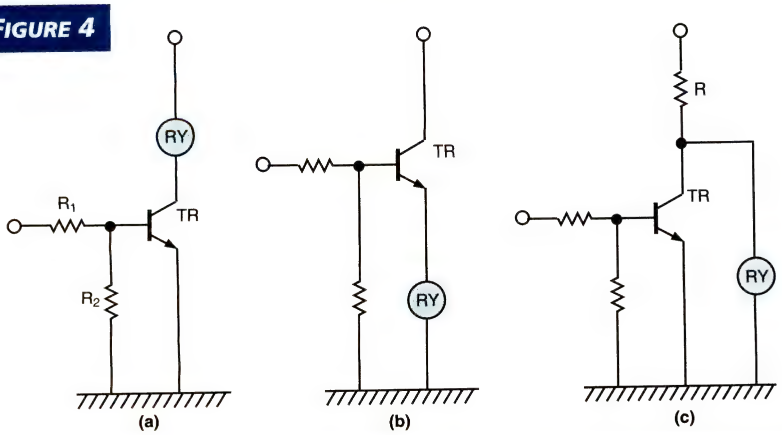
When considering relay circuitry, you should pay attention to the quality of the power source that drives the relay coils. **Fig 3** depicts a satisfactory common power-supply circuit, provided that the value of the smoothing capacitor is high enough, and the current drawn by the relay coil is not excessive. In general, the peak-to-peak ripple voltage should be less than 5%.

Fig 4 depicts several commonly used drivers for relay coils. Of the three circuits shown, you should use the one with the relay coil in the collector circuit (**Fig 4a**) to achieve good, stable operation. You can't guarantee correct relay operation for either the circuit with the relay coil in the emitter (**Fig 4b**) or the circuit with the relay coil parallel to the transistor (**Fig 4c**). For example, in the emitter-connection circuit, the transistor does not conduct completely, and the relay operation may be erratic.

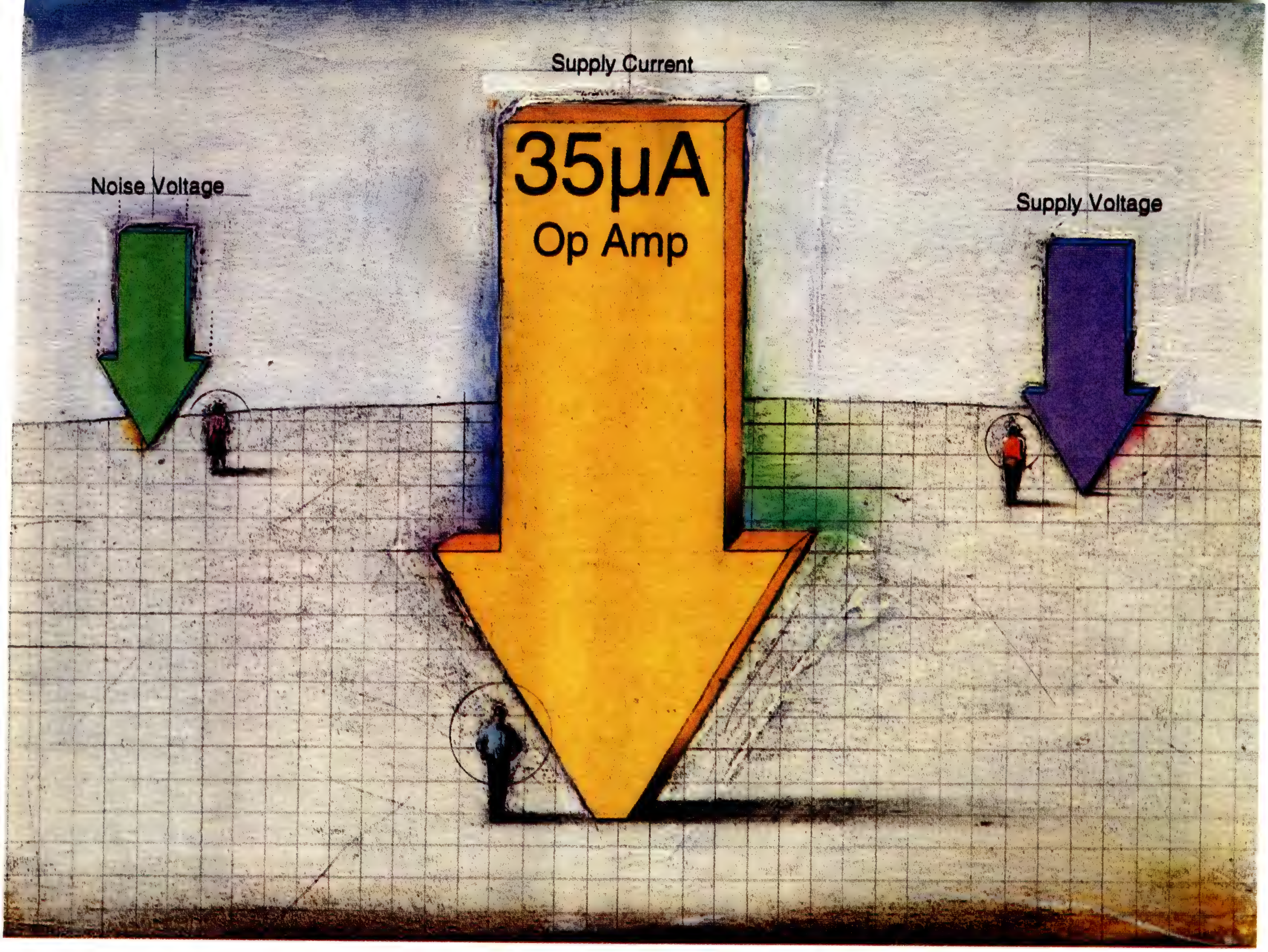
For best results, signals with fast rise and fall times should turn the EMRs on and off. EMRs don't operate as expected with coil voltages that ramp up slowly. When a sharp signal pulse isn't available, you should drive the coil with a simple Schmitt-trigger circuit.

Whenever a solid-state device drives a relay coil, take care to protect the solid-state device from the relay-coil inductive kickback. The kickback is a high voltage spike that the coil generates as its magnetic field collapses after the relay turns off. Because even low currents through inductive loads can produce voltage spikes of hun-

FIGURE 4



Each of these three circuit configurations can drive a relay coil. However, the configuration in (a) is recommended.



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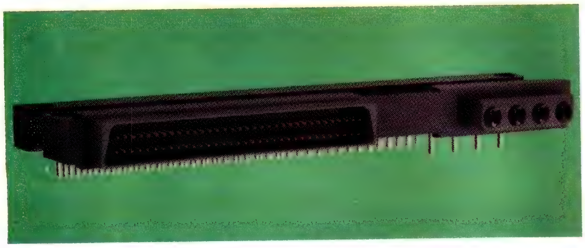

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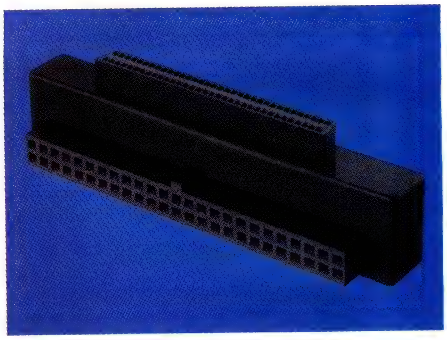

Meritec's SCSI-1 to SCSI-3 female-to-female right angle adapter allows interfacing between a SCSI-1 peripheral, like a hard disk drive, to a SCSI-3 controller card. The physical package consists of a 50-position .100 x .100 grid SCSI-1 female low density connector to a 68-position .050 x .100 grid SCSI-3 female high density connector. The short overall length between mating faces and the 90-degree right angle removes backplane packaging restrictions. The adapters are available with custom specified pinout and termination. Meritec P/N 980051.

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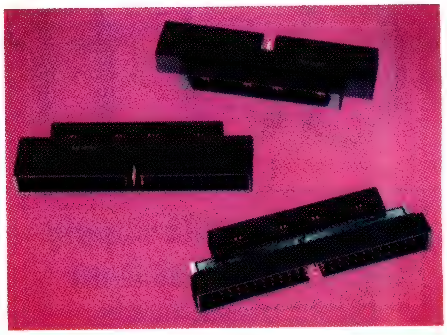

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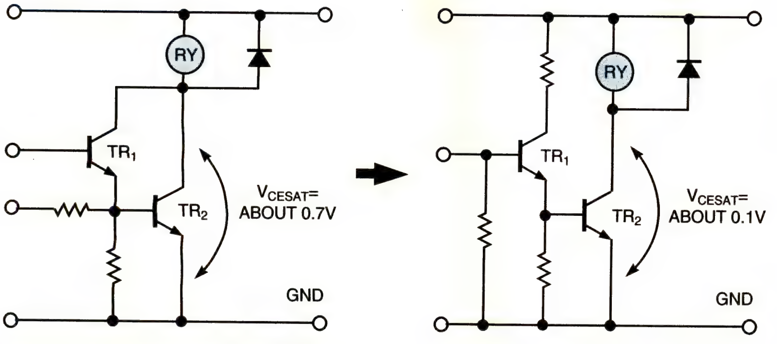
FIGURE 5



(a) (NO GOOD) DARLINGTON CONNECTION
(•DUE TO EXCESSIVE CONSUMPTION OF POWER, HEAT IS GENERATED)
(•A STRONG T_1 IS NECESSARY.)

(b) (GOOD) EMITTER CONNECTION
(T_2 CONDUCTS COMPLETELY.)
(T_1 IS SUFFICIENT FOR SIGNAL USE.)

You should avoid the Darlington connection in (a) because of a high V_{CESAT} when the driver is turned on. The emitter configuration in (b) produces the recommended low V_{CESAT}.

dreds of volts, an SSR without protection may burn on the first operation. The easiest way to suppress these spikes is to connect a diode across the coil as in **Fig 5**.

The Darlington trap

A trap that many designers fall into is placing a relay coil into the collector of a Darlington amplifier (**Fig 5a**). Relays generally require driving currents that are higher than the current that drives typical solid-state devices. Consequently, the high current amplification of the Darlington amplifier lures many users into this trap. The voltage drop across the two Darlington transistors in saturation in **Fig 5a** is approximately 0.7V. In the configuration in **Fig 5b**, the saturation voltage is approximately 0.1V. The difference in saturation voltage can be important in low-voltage circuits, such as a 3V dc circuit. In the Darlington connection in **Fig 5a**, the relay may not turn off.

The nature of a relay's load impacts its life. Relay loads fall into the following broad categories: resistive, inductive, capacitive, motor, lamp, and heater. Except for resistive loads, all loads require a good understanding of their nature and the application of suitable safeguards.

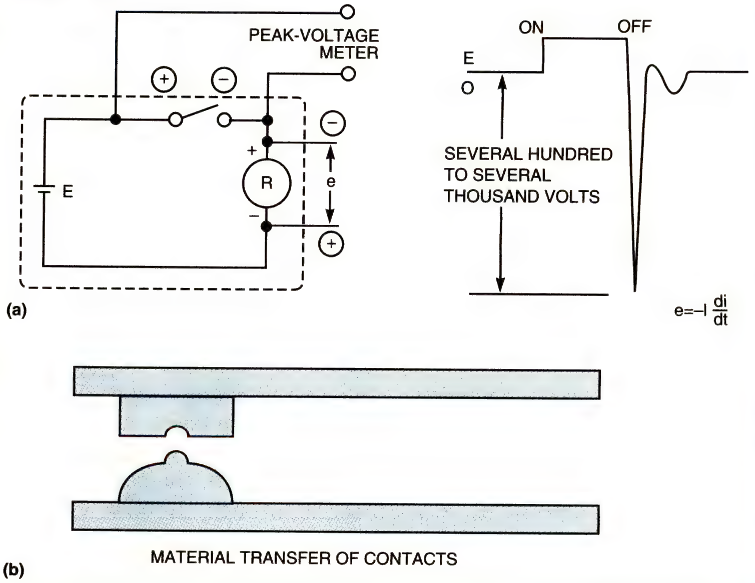
Interrupting current through any inductive load generates very high voltage spikes on the order of several hundred or thousand volts. Because these spikes can occur immediately upon contact opening, arcing can occur across this small gap and can continue as the contacts are drawn apart (**Fig 6**). As a result, contacts become pitted as melted material from one contact is transferred to the other contact. After a short time, these ball-and-socket shapes lock together, and the relay fails.

Over the years, manufacturers have developed a number of circuits to prevent the arcing problem. **Fig 7** illustrates some of the more popular options. The two RC circuits in **Figs 7a** and **b** suppress the high-voltage spike by storing the coil energy in the capacitor after the contacts open. The circuits then release the energy through the resistor after the contacts close. The diode in **Fig 7c** permits the coil energy to dissipate in the form of heat in the coil's dc resistance and the diode.

Circuit shortens release time

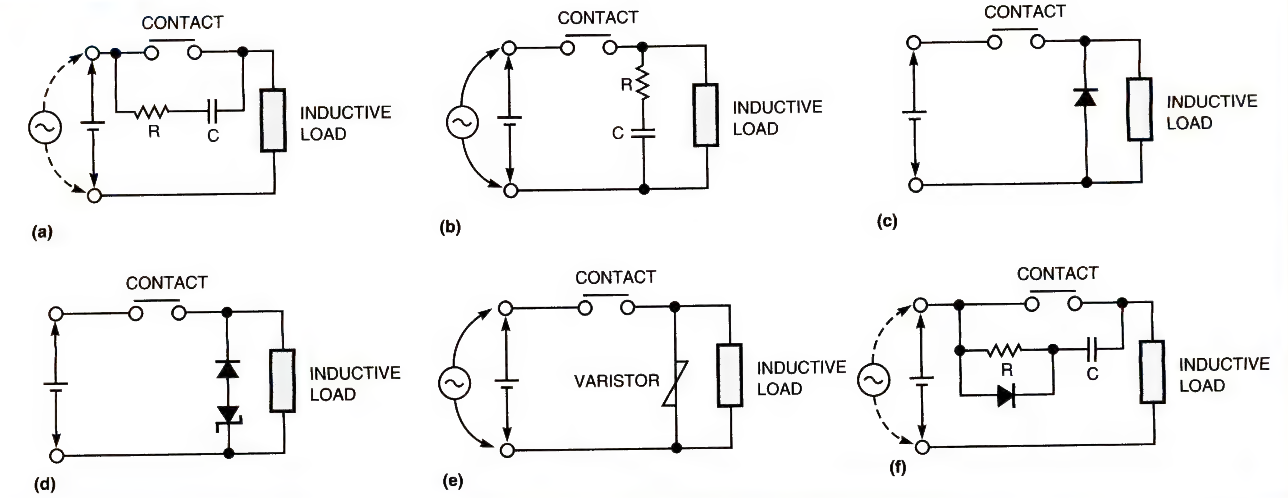
A problem with the circuits in **Figs 7a** through **e** is that they increase the release time of the load. If the load is a relay or a solenoid, the circuits' hold time increases because the coil current continues to flow via the arc-suppression circuit after the open-

FIGURE 6



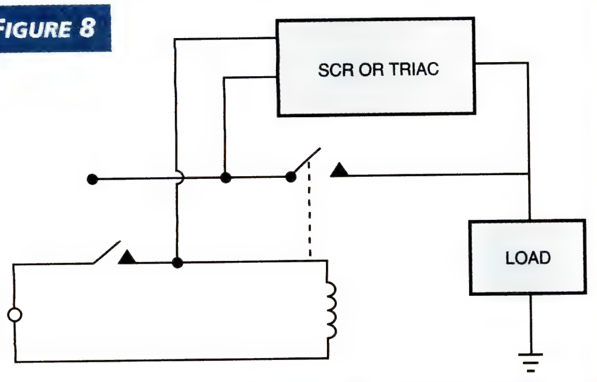
The voltage across the relay coil can reach hundreds of volts when the relay contacts open (a). Constant opening of the relay contacts can cause arcing, in which melted metal transfers from one contact to the other, eventually leading to failure (b).

FIGURE 7



Manufacturers have developed a variety of circuits to protect the relay and adjacent circuitry against the large voltage spike when the relay contacts open.

FIGURE 8



Connecting an SCR or Triac in parallel with a EMR can absorb the in-rush current that some loads, such as incandescent lamps, cause.

ing of the contacts. In applications that can't tolerate a long release time, you should consider the three-component circuit in **Fig 7f**. The circuit is basically an RC circuit with a diode across the resistor. When the contacts open, the coil energy quickly dumps into the capacitor through the low forward resistance of the diode. When the contacts close, the capacitor charge bleeds through the resistor, and the diode is now off.

If you do not protect the contacts, relays driving loads that cause high-in-rush currents can also quickly cause relay failure. Typical high-in-rush current loads include capacitors, motors, and incandescent lamps. Of the three types, incandescent lamps seem to be the most troublesome because the initial lamp load is a cold resistance and about one-tenth of its final hot value. A 1A lamp draws as much as 10A at turn on. If you use a relay with contacts rated at 2A to provide a safety factor of two, these contacts are overloaded by a factor of 5 every time the relay turns on.

A brute-force way to solve the in-rush problem is to use a relay with contacts rated to pass the in-rush current. A more elegant way is to use a device that can accommodate the in-rush current but not continuous loads, such as an SCR or a Triac. Once these devices handle the in-rush current, they hand the current over to a relay that maintains the steady-state condition (**Fig 8**). A switch that energizes the relay coil also fires an SCR connected across the relay contacts. Because the SCR is much faster than the relay, the SCR turns on and passes the heavy initial-surge current. By the time the relay contacts close, shorting out the SCR, the load current drops to a value that the relay contacts can handle.

Never connect EMRs in parallel

Under no circumstances should you connect parallel to handle higher currents. For example, never attempt to supply a 3A load with two relays in parallel that have 2A contact ratings. The relay contacts never close or open at exactly the same instant, so one relay is always overloaded. As **Table 1** notes, you can connect PhotoMOS relays in parallel but not the others.

In 1994, a significant development in PhotoMOS technology produced relays that can accommodate a variety of loads without any external protective circuitry. Designated "Soft-ON/OFF PhotoMOS relays," these devices combine the best features of EMRs, SSRs, and a variety of relay-protection circuits generally known as arc suppressors or snubbers. Tran-

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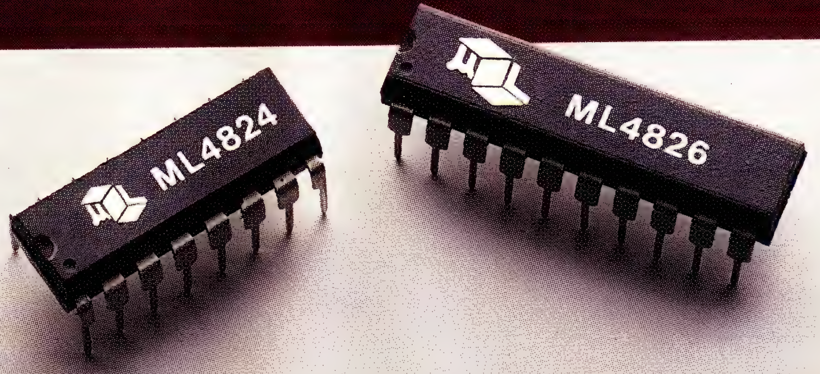

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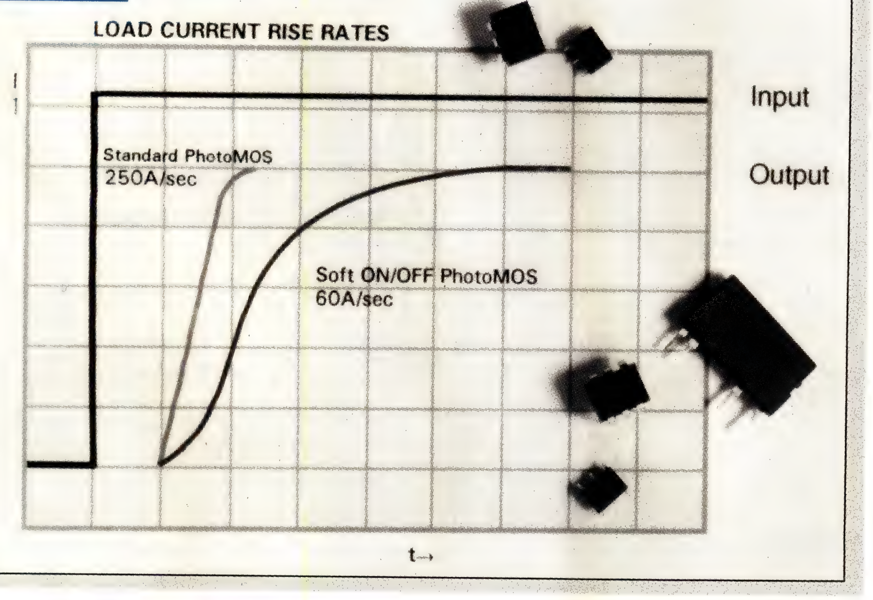
sients internally add circuitry to the standard PhotoMOS relay that extends the relay's rise and fall times, and they dissipate before damaging either the relay or the external components.

Fig 9 shows a curve of a current rise's rate into a resistive load to be approximately 250 A/sec when switched by a standard PhotoMOS relay. When the Soft-ON/OFF PhotoMOS switches current into the same load, the rate of current rise is more than four times less (60 A/sec). When the current turns off to the resistive load, the load-current fall rate is 50,000 A/sec for the standard PhotoMOS relay and only 125 A/sec for the Soft-ON/OFF PhotoMOS relay.

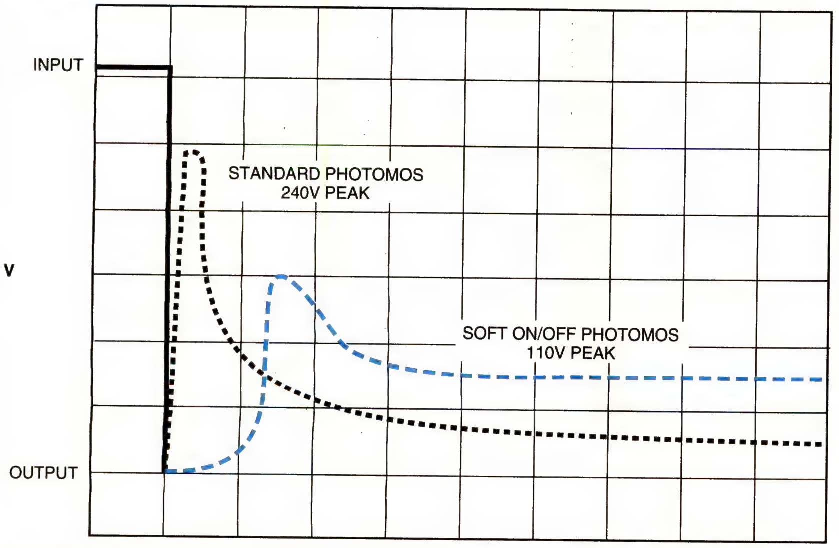
Fig 10 shows a 240V spike that occurs when turning off an inductive load by means of a conventional PhotoMOS relay. The spike is reduced to 110V when turning off the load with a Soft-ON/OFF PhotoMOS relay. In addition to the lower spike amplitude, the Soft-ON/OFF PhotoMOS relay delays the spike and stretches it in time, which helps to reduce its impact on the switching device and surrounding components.

FIGURE 9



A Soft-ON/OFF PhotoMOS relay switches current to the load with a much slower rise time than a standard PhotoMOS relay.

FIGURE 10



When turning off an inductive load with a standard PhotoMOS relay, a large (240V) voltage spike can occur as the field in the inductor collapses. A Soft-ON/OFF PhotoMOS relay can delay and lower the peak voltage of the spike (110V).

Work with the vendor

To ensure success of your relay circuit, you should work closely with the relay vendor. Develop strategic partnerships with your chosen relay vendor in which the companies involved cooperate in various stages of design (particularly in the early stages), manufacturing, and quality control. In these partnerships, you get an accurate, up-to-date perspective on state-of-the-art component technology, including future products. A partnership puts the relay vendor in direct contact with your company's problems and expectations. EDN

Author's biography

Doug Lionetti is a marketing manager for the Aromat Corp in New Providence, NJ, where he has worked for 2½ years. Lionetti helped to develop the T-series signal relays and PhotoMOS SSRs. Lionetti holds a BS in electrical engineering and an MS in management science from the Stevens Institute of Technology, Hoboken, NJ. In his spare time, he enjoys golf, photography, and bicycling.

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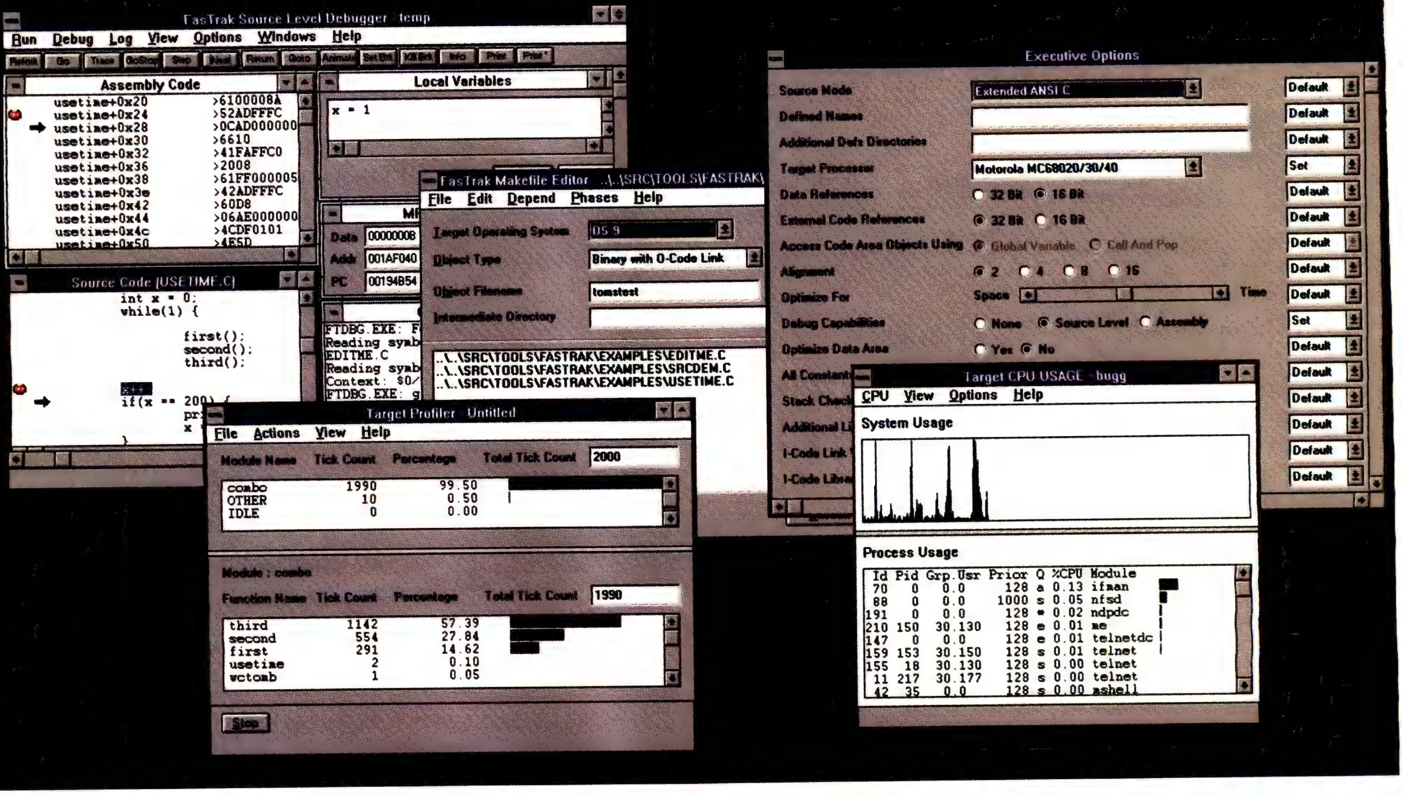
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Retnrn Go Trace GoStep Step Next Return Goto Animate Set Brk Kill Brk Info Print Print*
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Local Variables
Source Code [USETIME.C]
FasTrak Makefile Editor ..\..\SRC\TOOLS\FASTRAK\
File Edit Depend Phases Help
Target Profiler - Untitled
File Actions View Help
Stop
Executive Options
Target CPU USAGE - bugg
CPU View Options Help
System Usage
Process Usage

```
usetime+0x20          >6100008A
usetime+0x24          >52ADFFFC
usetime+0x28          >0CAD000000
usetime+0x30          >6610
usetime+0x32          >41FAFFC0
usetime+0x36          >2008
usetime+0x38          >61FF000005
usetime+0x3e          >42ADFFFC
usetime+0x42          >60D8
usetime+0x44          >06AE000000
usetime+0x4c          >4CDF0101
usetime+0x50          >4E5D
```

```
x = 1
```

Data 00000008
Addr 001AF040
PC 00194854

```
int x = 0;
while(1) {

        first();
        second();
        third();

x++;
if(x == 200) {
        pr
        x
}
```

```
FTDBG.EXE: F
Reading symb
EDITME.C
Reading symb
Context: $0/
FTDBG.EXE: g
```

Target Operating System: OS 9
Object Type: Binary with 0-Code Link
Object Filename: tomstest
Intermediate Directory:

```
..\..\SRC\TOOLS\FASTRAK\EXAMPLES\EDITME.C
..\..\SRC\TOOLS\FASTRAK\EXAMPLES\SRCDEM.C
..\..\SRC\TOOLS\FASTRAK\EXAMPLES\USETIME.C
```

Module Name Tick Count Percentage Total Tick Count 2000

```
combo          1990      99.50
OTHER            10       0.50
IDLE              0       0.00
```

Module : combo

Function Name Tick Count Percentage Total Tick Count 1990

```
third          1142      57.39
second          554      27.84
first           291      14.62
usetime           2       0.10
wctomb            1       0.05
```

Source Mode: Extended ANSI C — Default
Defined Names: — Default
Additional Defs Directories: — Default
Target Processor: Motorola MC68020/30/40 — Set
Data References: ○ 32 Bit ● 16 Bit — Default
External Code References: ● 32 Bit ○ 16 Bit — Default
Access Code Area Objects Using: ● Global Variable ○ Call And Pop — Default
Alignment: ● 2 ○ 4 ○ 8 ○ 16 — Default
Optimize For: Space … Time — Default
Debug Capabilities: ○ None ● Source Level ○ Assembly — Set
Optimize Data Area: ○ Yes ● No — Default
All Constant — Default
Stack Check — Default
Additional Li — Default
I-Code Link — Default
I-Code Libra — Default

```
 Id Pid Grp.Usr Prior Q %CPU Module
 70   0   0.0     128 a 0.13 ifman
 88   0   0.0    1000 s 0.05 nfsd
191   0   0.0     128 * 0.02 ndpdc
210 150  30.130   128 e 0.01 me
147   0   0.0     128 e 0.01 telnetdc
159 153  30.150   128 s 0.01 telnet
155  18  30.130   128 s 0.00 telnet
 11 217  30.177   128 s 0.00 telnet
 42  35   0.0     128 s 0.00 mshell
```

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Emulator for nX 65K series microcontrollers. The iceMaster 65K from MetaLink Corp is an in-circuit emulator for use with Oki Semiconductor's nX 65K series microcontrollers. The emulator requires a PC host computer and supports symbolic and source-level debugging. Operating over the same 2.7 to 5.5V range as the microcontroller, the emulator lets you simulate operations under the same voltage conditions you expect to use in your target system. $2995. **Oki Semiconductor**, Sunnyvale, CA. (408) 720-1900.

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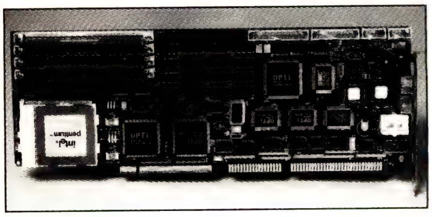

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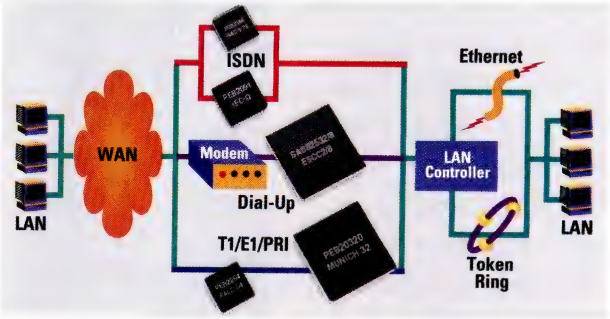

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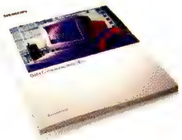

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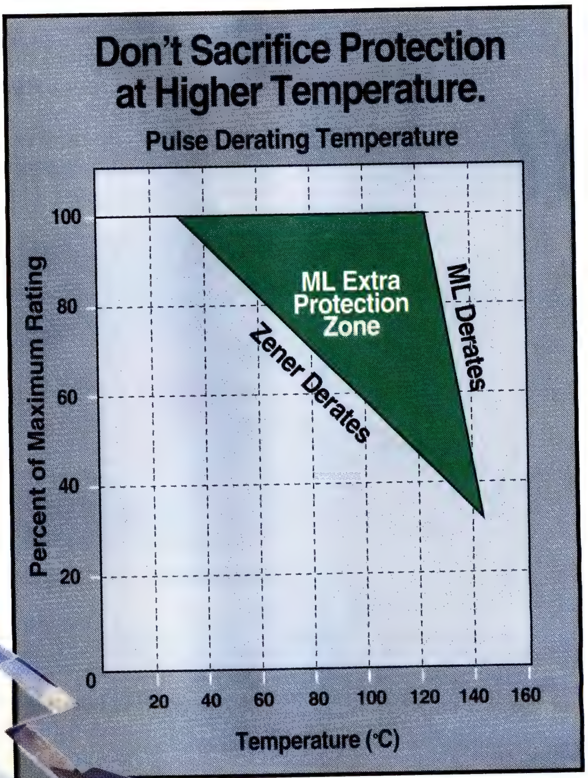

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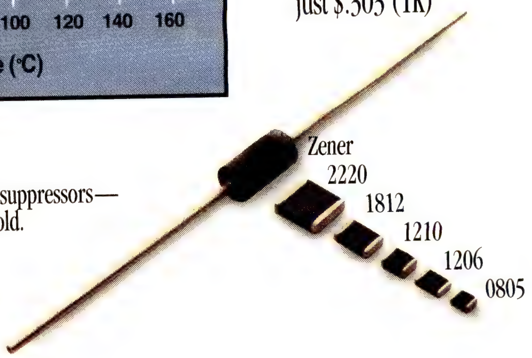

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DLL provides DSP, math, and data acquisition for C/C++, Visual Basic, and MatLab programs. The DSPower-HWLib, a Windows dynamic link library (DLL), interfaces to standard DSP and data-acquisition hardware for user-defined C/C++, Visual Basic, and MatLab programs. Low-level functions include board control, block-memory transfers, DSP-executable file download, and others. High-level functions include data acquisition, waveform record and playback, signal synthesis, stimulus and response measurement, and DSP/math functions. DSPower-HWLib costs $995. **Signalogic**, Dallas, TX. (214) 343-0069. **Circle No. 422**

Adapters and disassemblers for μPs expand logic-analyzer support. The PM 3585 logic-analyzer series (starting at $5385) now supports 100 μPs. The new adapters and disassemblers are the PF8616/32 ($1280) for the Motorola 68HC11 PLCC, the PF8743/34 ($1790) for the Motorola 68306 PQFP, the PF8755/37 ($1850) for the Zilog Z84X15 QFP, the PF 8754/32 ($1600) for the Zilog Z84X13 PLCC, the PF 8747/37 ($2300) for the Siemens SAB-C167P MQFP, the PF8618/32A ($1500) for the Siemens 80C515A/35A PLCC, and the PF8710/32 ($1440) for the Thomson ST903X/4X PLCC. 15-mm extension sockets for the Z84X13 PLCC and ST903X/4X PLCC cost $145. **Fluke Corp**, Everett, WA. (206) 347-6100. **Circle No. 423**

VME/VXI card provides four MIL-STD-1553 channels. The BU-65528 provides four independent channels of MIL-STD-1553 terminal communications on one double-Eurocard (6U) board. Each channel is based on the company's BU-61580 ACE hybrid. You can individually configure each channel as a bus controller, a remote terminal, or a bus monitor. The boards cost $4195 with a single channel and $9895 with four channels. **ILC Data Device Corp**, Bohemia, NY. (516) 567-5600. **Circle No. 424**

Development and debugging environment for Motorola 68302 family. The SingleStep product includes integration with C/C++ compilers from the vendor and other companies, including Diab Data, Intermetrics, and Microtec Research. The tool also provides kernel awareness for many real-time operating systems, such as C Executive, Nucleus, pSOSystem, RTXC, and SuperTask. Prices for the tool start at $1500 for a single-user license. **Software Development Systems**, Oak Brook, IL. (708) 368-0400. **Circle No. 425**

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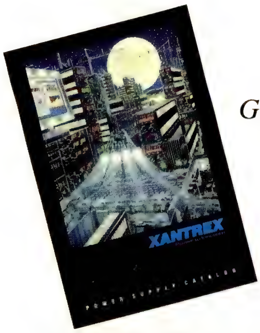

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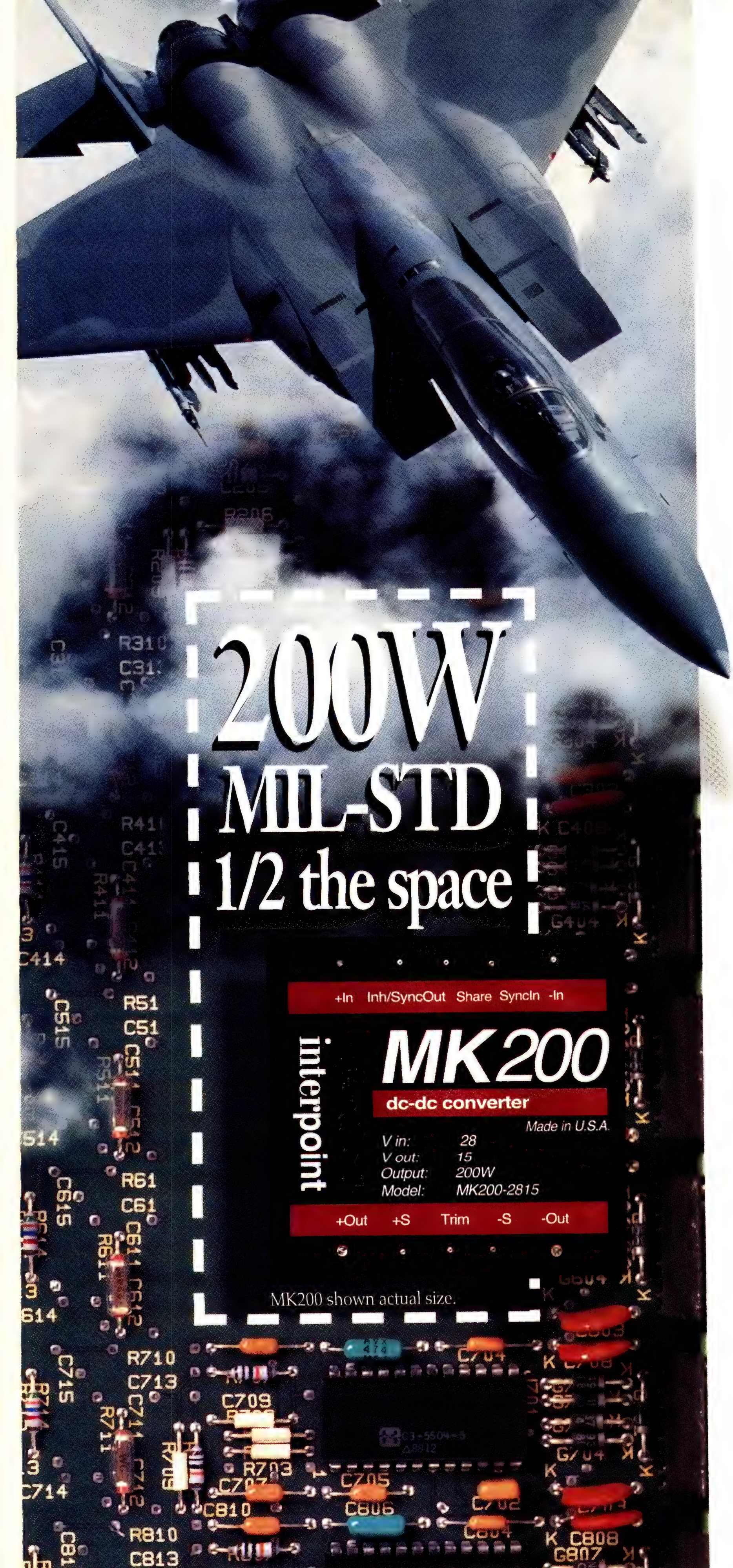
CIRCLE NO. 49



MK200 shown actual size.

Introducing Interpoint's new high-density, high-performance MK200 dc-dc converter.

If you're designing power supplies into military or aerospace systems, the new MK200 Series will put uncompromising performance on your board.

SINGLE			DUAL		
Vout Single	Output Current	Ripple mVp-p	Vout Dual	Output Current	Ripple mVp-p
5	30A	10	±12	±7.1A	50
12	14.1A	20	±15	±6.7A	60
15	13.3A	25			

1 MHz operating frequency (fixed) • 500V, 100 Mohm isolation • 150 grams weight • 2.4 x 2.28 x 0.45 in. (61.0 X 57.9 X11.4 mm) • 16 to 40 or 19 to 40 Vdc input • Wide range output trim

They provide the industry's highest usable power density: 80W/in^3, from -55° to +125° C with no external components. That's up to a full 200 watts of output power in a low-profile, standard-pinout part half the size of "the brick". Internal filtering and low noise levels eliminate external filters. Efficiencies up to 90% drastically reduce heat sink requirements.

These high reliability dc-dc converters are packaged in six-sided sealed metal cases and utilize hermetically sealed silicon. They meet MIL-STD-810 environmental standards, and are tested to the stringent thermal shock conditions of MIL-STD-202.

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CIRCLE NO. 146

FREE INFO, FREE POSTAGE
Use our postage-paid reader-service cards to get more information on any of these products.

Core-logic chip set for Pentium provides multimedia features. According to the company, the Viper-M chip set frees about 40% of the system bandwidth for multimedia applications. To improve CPU/memory bandwidth for audio transfers, the chip set has an integrated Type F DMA interface. The chip set also has an integrated bus-master IDE controller, allowing IDE devices, such as a hard-disk drive or a CD-ROM to transfer data with little help from the CPU. The three-chip set is pin-compatible with other Viper chip sets and costs $30 (10,000). **Opti Inc**, Santa Clara, CA. (408) 980-8178, ext 850. **Circle No. 332**

2-D 3×3 convolver has nine multipliers and two internal, 1k-word-deep data-line buffers. Designed for video-imaging applications, the DSP chip executes 3×3 kernel convolutions (2-D filtering) at real-time video rates.

According to the company, the device provides all data manipulations for high-quality edge detection, texture enhancement, and detail smoothing of video images. $48 (100). **Logic Devices Inc**, Sunnyvale, CA. (408) 737-3300. **Circle No. 333**

Translators convert between TTL and ECL formats. The E-Lite family of translators is available in 10 versions. Conversion formats include TTL, differential ECL, and differential positive ECL. Each function is compatible with 10KH and 100K logic families. The devices come in an eight-lead SOIC package and cost $2.60 (5000). **Motorola Semiconductor Products Sector**, Phoenix, AZ. (602) 732-3410. **Circle No. 334**

CMOS logic reduces ground bounce, eliminates need for termination resistors. The 74FCT166-XXXT CMOS light-drive devices reduce ground bounce by as much as 75% compared with high-drive devices. According to the company, a typical light-drive device has a ground bounce of less than 250 mV at 5V. Eliminating the need for termination resistors reduces cost, power consumption, and board space. The 74FCT166244T offers 6.5-, 4.8-, and 4.1-nsec propagation delays. From $1.50 (10,000). **Integrated Device Technology**, Santa Clara, CA. (800) 345- 7015. **Circle No. 335**

Stand-alone, secondary cache-controller chip for IDT R4600 and R4700 64-bit RISC processors. The GT-64012 lets you add a secondary

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It's not just the small package size that's making our LMOS logic so big.

Or its full compatibility with conventional logic.

Or even the multiple gates, 1-5V operation, tape and reel packaging, high-speed switching and factory capacity.

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Along with the fact that LMOS lets designers sneak logic in wherever there's a big need.

Or a little bit of room.

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SPD-94-075A

cache to a system without changing the system's ASICs or controller logic. The controller offers write-through, direct-mapped, 32-byte line size and is essentially transparent to the system. It supports up to 50-MHz bus-clock speeds with no wait states. The device is compatible with industry-standard synchronous-burst SRAMs. It comes in a 44-pin PLCC and costs $22.50 (10,000). The Galileo-2 evaluation module and reference design cost $995 and includes 512 kbytes of cache. **Galileo Technology Inc**, San Jose, CA. (408) 451-1400.
Circle No. 336

8000-gate FPGA is PCI-compliant in all speeds. The CY7C387A/388A complies with the Peripheral Component Interconnect (PCI) Revision 2.0 specification. The devices use QuickLogic's nonvolatile Vialink antifuse technology for programming and feature chip-to-chip operating frequencies as high as 110 MHz. Input, logic-cell, and output delays are <6 nsec. The 387A has 114 I/O pins and eight input/clock pins in a 144-pin TQFP. The 388A has 172 I/O pins and eight input/clock pins in a 208-pin PQFP. From $92.75 (100). **Cypress Semiconductor**, San Jose, CA. (408) 943-2600.
Circle No. 337

Switch-mode controller IC features operation to 1 MHz. The Si9145 switch-mode controller's high operating frequency lets you use small-outline, surface-mount inductors and capacitors for minimum pc-board area. The device is guaranteed to operate down to 2.7V and has a minimum start-up voltage of 3V, making it suitable for lithium-ion, NiCd, and nickel-metal-hydride battery packs. Typical power consumption is 1 mA at 1 MHz and 250 μA in standby mode. The device comes in an SO-16 package for $1.64 (100,000) and a TSSOP-16 package for $1.87 (100,000). **Siliconix**, Santa Clara, CA. (800) 554-5565, ext 50.
Circle No. 338

12-bit, 50-kHz sampling ADC draws 3.5 mA from a 5V supply. The HI5816 serial-output A/D operates from a 3 to 6V supply. The converter has ±0.75-LSB accuracy over a –40 to +85°C temperature range. An integral track-and-hold amplifier has a 1-MHz input bandwidth. The converter is available in 16-pin DIP, SOIC, and SSOP packages. All versions cost $5.14 (1000). **Harris Semiconductor Corp**, Melbourne, FL. (800) 442-7747, ext 7313.
Circle No. 339

Voltage-feedback op amp has 1500-V/μsec slew rate and 750-MHz unity-gain bandwidth. The CLC440 suits a variety of high-speed applications. It has a differential gain of 0.015% and a differential phase of 0.025°. Input noise is 2.5 nV/$\sqrt{\text{Hz}}$ and 3.5 pA/$\sqrt{\text{Hz}}$. The amplifier operates from a single 5 to 12V supply, and quiescent power dissipation is 70 mW from a 5V supply. Output drive is 90 mA. The device is available in eight-pin DIP and SOIC packages. $4.20 (1000). **Comlinear Corp**, Fort Collins, CO. (303) 226-0500.
Circle No. 340

IC products continued on pg 147

High Stability Ovenized Oscillator

The SC10 10 MHz quartz oscillator uses an SC cut crystal to provide an extremely low aging rate, high thermal stability and very low phase noise. For the most critical frequency and timing applications, the SC10 is the ultimate solution.

Grade		J	K	A
Aging		$<1\times10^{-9}$/day	$<5\times10^{-10}$/day	$<2\times10^{-10}$/day
Thermal Stability (0-50° C)		$<\pm2\times10^{-9}$	$<\pm1\times10^{-9}$	$<\pm5\times10^{-10}$
Phase Noise:	10 Hz	<-120 dBc/Hz	<-125 dBc/Hz	<-130 dBc/Hz
	100 Hz	<-150 dBc/Hz	<-150 dBc/Hz	<-150 dBc/Hz
	1 kHz	<-155 dBc/Hz	<-155 dBc/Hz	<-155 dBc/Hz
Operating Range		0° to 50°C	-10° to +60°C	-20° to +70°C
Allan Variance (1 second)		$<1\times10^{-11}$	$<5\times10^{-12}$	$<2\times10^{-12}$

- SMD construction
- Electronic and mechanical frequency tuning
- +15 or +24 VDC operation
- Pin, SMA, SMB or SMC connectors
- Size: 2" x 2" x 4"
- $250 base price for J grade (quantity of 100)

STANFORD RESEARCH SYSTEMS, INC.
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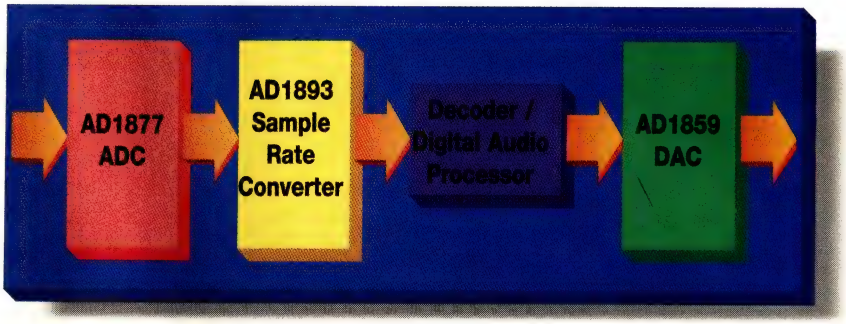
CIRCLE NO. 66

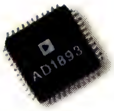
CD-Quality Audio Converters At Prices That Sound Even Better.

When leading OEMs design tomorrow's audio products, they naturally talk to Analog Devices about high-performance digital audio ICs with true CD quality. For example, the ADC, sample-rate converter and DAC listed below all offer better than 90 dB dynamic range, dual channels and many unique multimedia audio features – all at low consumer OEM prices.



AD1877 ADC. This single-supply 16-bit sigma-delta stereo ADC provides 92 dB signal-to-noise ratio and -90 dB THD+N. Analog inputs are single-ended for easier use. A flexible serial data interface has eight user-selectable modes. There's even a 10 µW power down mode. Other applications include general-purpose data acquisition, communication systems and medical electronics. A -55° C to 105° C temperature-screened version is also available. Priced from $10.00.*

SAMPLEPORT



AD1893 ASRC. This SamplePort® stereo asynchronous sample rate converter has 96 dB dynamic range and -96 dB THD+N at 1 kHz. Our patented technology allows conversion over 1:2 or 2:1 sample frequency range and rejects sample clock jitter. Low power 3 V operation is perfect for portable applications like MiniDisc, CD-R and DAT. Prices start at $10.10.*

AD1859 DAC. This single-supply 18-bit integrated stereo DAC has 96 dB dynamic range, and -90 dB THD+N. A unique digital phase-lock loop accepts a 27 MHz master clock input and sample rates from 28 to 52 kHz, without external components. It's ideal for digital cable and DBS settop decoders, HDTV, CD players and high-end computer multimedia. Prices start at $7.00* for both SOIC and SSOP versions.

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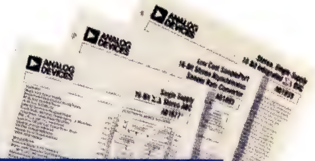
AD1877	Faxcode 1074
AD1893	Faxcode 1821
AD1859	Faxcode 1853



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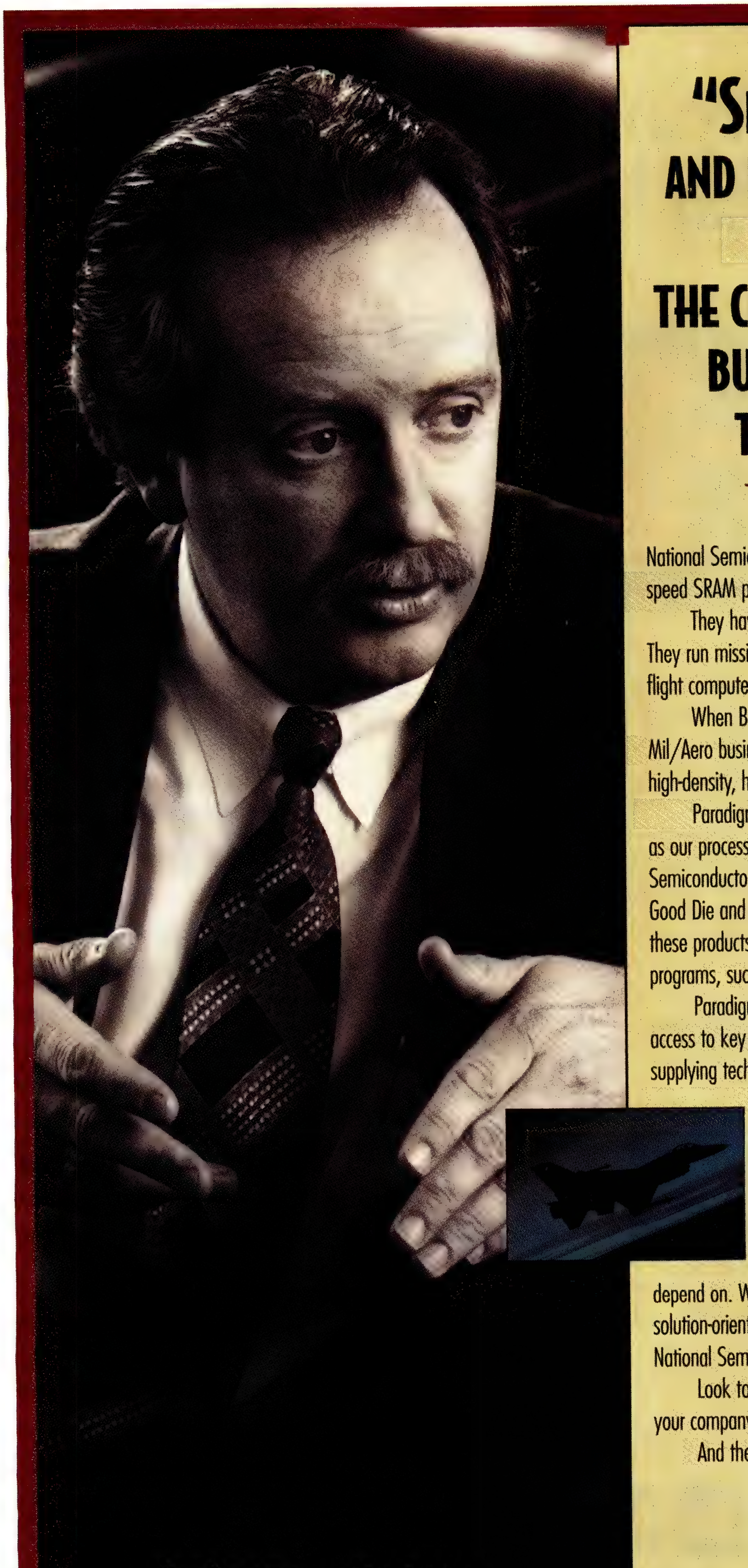

BRAD PAULSEN, Director of Sales & Marketing,
Mil/Aero Division, National Semiconductor

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CIRCLE NO. 165

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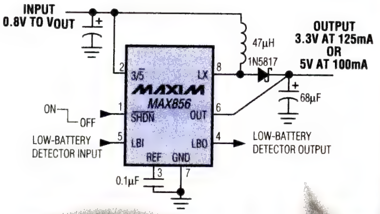
No. 30

BATTERY-SAVING SOLUTIONS FOR EVERY PIECE OF YOUR HAND-HELD EQUIPMENT'S POWER SUPPLY

Step Up 2 Cells to 3.3V or 5V

Input: 0.8V to 5.5V
Output: 3.3V, 5V, or adj. (2.7V to 6V)
Up to 125mA

- 85% Efficiency
- µMAX Package (1.1mm High)
- 25µA Supply Current
- 1µA Shutdown
- $1.60† (MAX856-MAX859)
- MAX856EVKIT-MM
- See also: MAX856-MAX859 & MAX756/MAX757 (250mA)



INPUT 0.8V TO VOUT
47µH
1N5817
OUTPUT 3.3V AT 125mA OR 5V AT 100mA
68µF
MAXIM
MAX856
2
3/5
8
LX
1
SHDN
6
OUT
5
LBI
4
LBO
REF
GND
3
7
0.1µF
ON
OFF
LOW-BATTERY DETECTOR INPUT
LOW-BATTERY DETECTOR OUTPUT

µMAX
0.024in²
(1.11mm High)

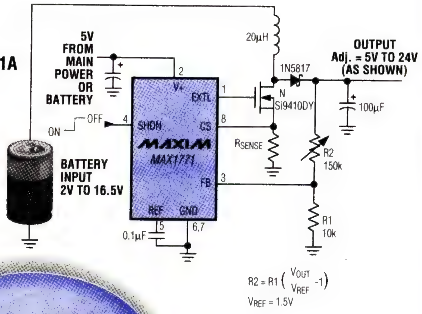
8-SOIC
0.048in²
(1.75mm High)

Circle No.
186

24V Positive LCD Bias Supply

Input: 2V to 16.5V
Output: 5V to Unlimited
Up to 10W

- >90% Efficient from 10mA to 1A
- 110µA (max) Supply Current
- 5µA (max) Shutdown
- Voltage Limited Only by External Power FET V_{GS}
- 300kHz Current-Limited PFM Control
- $1.80†
- See also: MAX1771 & MAX770-MAX773

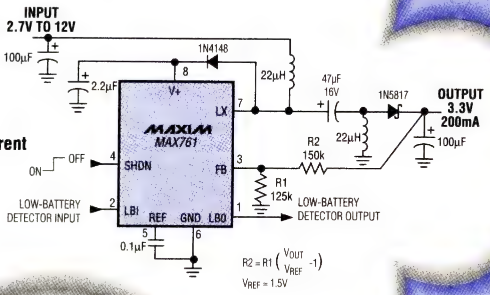


Circle No.
187

Step Up/Down 3 Cells or 4 Cells to 3.3V or 5V

Input: 2.7V to 12V
Output: Adj. (1.5V to 6V)
Up to 200mA

- Step-Up/Down Without Transformer
- 85% Typical Efficiency
- 100µA (max) Quiescent Current
- 5µA (max) Shutdown
- No Leakage Through Diode in Shutdown
- $2.23†
- See also: MAX761/762, MAX1771 & MAX877/878/879



Circle No.
188

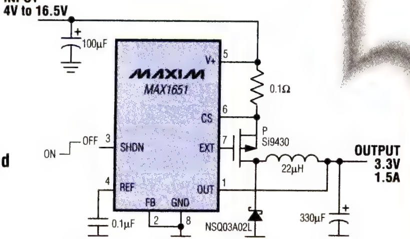
LOW-POWER HAND-HELD DEVICES

- Organizers
- Palmtops
- Medical Meters
- Remote Controls
- Voice Pagers & Recorders

Step Down 4-Cell to 8-Cell Inputs to 3.3V or 5V

Input: 3.5V to 16.5V
Output: 3.3V, 5V, or adj. (2.7V to V_{IN})
Up to 2A

- >90% Efficiency from 10mA to 1.5A
- 100µA (max) Supply Current
- 5µA (max) Logic-Controlled Shutdown
- 8-Pin SOIC
- 300kHz Current-Limited PFM Control
- $1.60†
- MAX1649EVKIT-SO
- See also: MAX1649/MAX1651

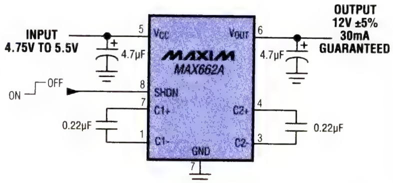


Circle No. 189

5V & 12V Flash Memory Programmers Use No Inductors—Fit in 0.1in²

Input: 4.5V to 5.5V (MAX662A)
2V to 3.6V (MAX619)
Output: 12V @ 35mA (MAX662A)
5V @ 50mA (MAX619)

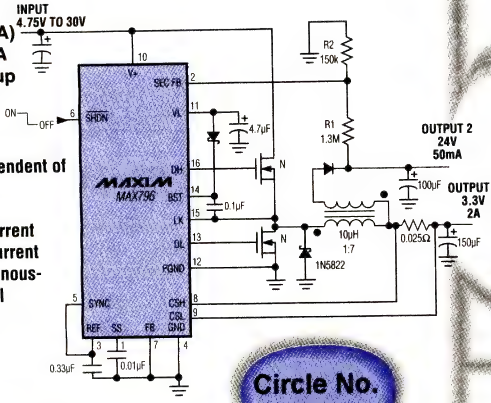
- 185µA Supply Current (MAX662A)
- 75µA Supply Current (MAX619)
- 0.5µA Logic-Controlled Shutdown
- $2.09† (MAX662A)
- $1.60† (MAX619)
- MAX662AEVKIT-SO
  MAX619EVKIT-SO



Circle No. 190

Supply 3.3V & 24V from 5-Cell to 30V Inputs

Input: 4.5V to 30V
Output: 3.3V @ 2A
(or up to 10A)
24V @ 50mA
(adj. 5V & up
@ 150mA)



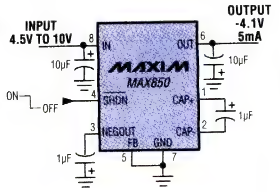
- Optional Dual Output from Single IC
- Secondary Load Independent of Primary Load
- >90% Efficiency
- 300µA (typ) Supply Current
- 3µA (typ) Shutdown Current
- All N-Channel Synchronous-Rectified PWM Control
- 16-Pin Narrow SOIC
- $3.65†
- MAX796EVKIT-SO
- MAX797EVKIT-SO
- See also:
MAX796-MAX799 & MAX767

Circle No. 191

Complete GaAsFET Bias Supply in One 8-Pin SOIC

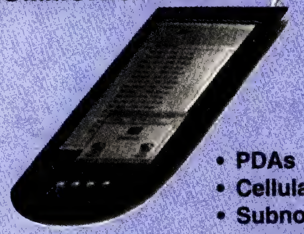
Input: 4.5V to 10V
Output: -4.1V @ 5mA or adj. (-1.2V to -9V)

- Fits in 0.1in²
- Replaces 8 Components & 2 ICs
- Low-Noise: 2mVp-p Output Ripple
- 1µA (max) Shutdown Current
- 8-Pin SOIC
- $1.65†
- MAX850EVKIT-SO
- See also:
MAX850-MAX853



Circle No. 192

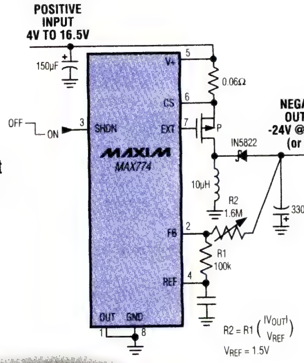
HIGH-POWER WIRELESS COMMUNICATORS



- PDAs
- Cellular Phones
- Subnotebooks
- Personal Digital Communicators

Negative LCD Bias Supply Is 83% Efficient

Input: 3V to 16.5V
Output: 0V to Unlimited
Up to 1A



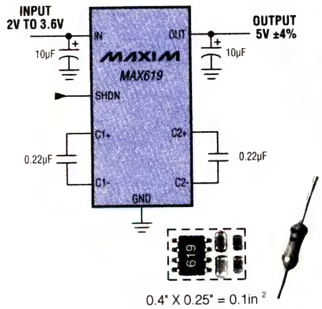
- 83% Efficient from 10mA to 200mA @ -24V
- 100µA (max) Supply Current
- 5µA (max) Logic-Controlled Shutdown
- 8-Pin SOIC
- 300kHz Current-Limited PFM Control Scheme
- $2.20†
- MAX774EVKIT-SO
- See also:
MAX775/MAX776 & MAX749

Circle No. 193

Compact 5V Backup Supply Fits in 0.1in²

Input: 2V to 3.6V
Output: 5V @ 50mA ($V_{IN} \geq 3V$)
5V @ 20mA ($V_{IN} \geq 2V$)

- No Inductors
- 1µA (max) Logic-Controlled Shutdown
- 75µA (typ) Supply Current
- Inexpensive: $1.60†
- MAX619EVKIT-SO
- See also:
MAX619

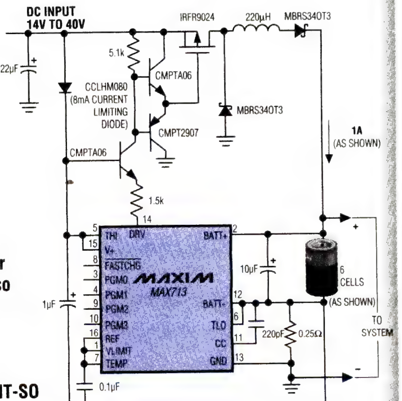


0.4" X 0.25" = 0.1in²
(RESISTOR SHOWN FOR SCALE)

Circle No. 194

Complete Charger in 16-Pin Narrow SOIC

Input: 7V to 40V
Output: 1 to 16 Cells
Up to 3A



- High-Current (over 1A)
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- Linear Regulator Applications Also Available
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Circle No. 195

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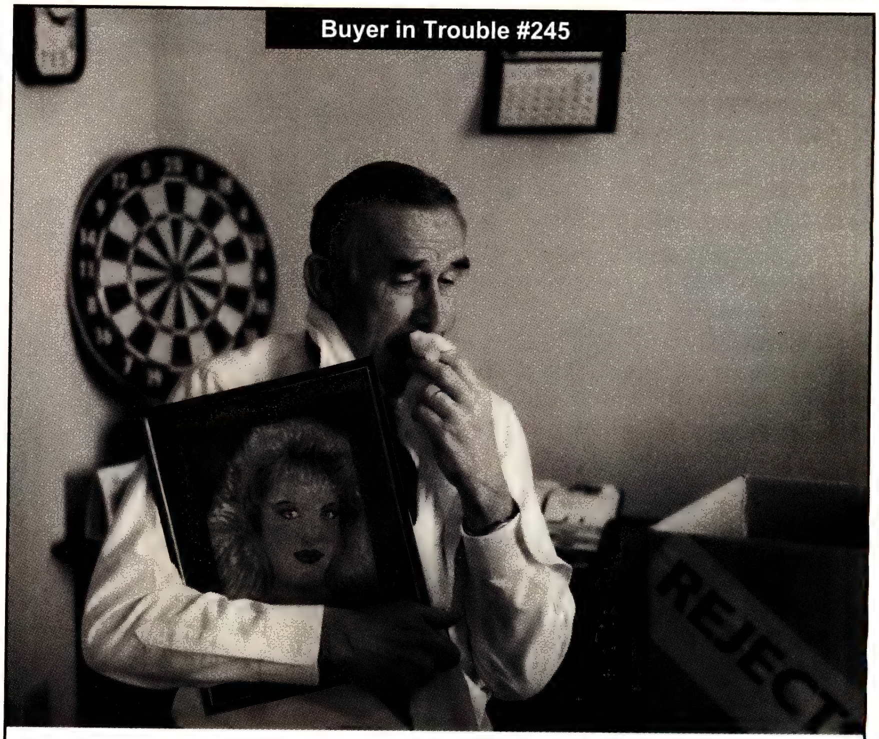
600k-sample/sec, 12-bit A/D converter draws 60 mW typ. The LTC1279 A/D converter includes a 200-nsec sample/hold circuit, a voltage reference, an internally trimmed conversion clock, and a parallel interface for DSP and µP ports. The device converts 0 to 5V signals using a single 5V supply or ±2.5V signals using ±5V supplies. It provides 11.3 effective bits of resolution at the Nyquist frequency and has a ±1-LSB integral nonlinearity error. The internal clock automatically synchronizes with each sample command, reducing asynchronous-clock-noise problems. A power-down mode uses 8.5 mW and provides instant wake-up. The converter is available in 24-pin DIP and SOIC packages and costs $13 (1000). **Linear Technology Corp**, Milpitas, CA. (408) 432-1900. **Circle No. 341**

Programmable switch provides 48 I/O ports and a 2.4-Gbps bandwidth. The PS48 has a parallel data bus providing direct access to the configuration memory. The switch uses a crossbar architecture in which each I/O port is identical to the others, and you can program them for input, output, or bidirectional operation. The device supports flow-through, clocked (to 100 MHz), and analog-signal flow with identical delays. The switch permits one-to-one and one-to-many connections. You can make or break individual or bus-wide connections in 30 nsec or less. You can also change any connection without affecting any other connection. $38 (1000). **I-Cube Inc**, Santa Clara, CA. (408) 986-1077.
Circle No. 342

Hardware and software for V.34 modem. The MDSP2780 processor and software simplify implementation of the open MWave V.34 modem standard. The standard accommodates 2.4- to 28.8-kbps data rates in 2.4-kbps increments. The MDSP2780 with audio, communications, and voice functions costs $43 (OEM). **IBM Microelectronics**, Hopewell Junction, NY. (800) 769-3772. **Circle No. 343**

Dual 12-bit serial DAC in space-saving 1.5-mm-high SOIC-14 package. The AD8522 single-supply 5V DAC draws 5 mW typ. The DAC provides a maximum ±1.5-LSB integral nonlinearity, has its own 2.5V reference, a 4.096V full-scale output, and ±5-mA current drive. Serial data can clock in at 14 MHz. $8.36 (1000). **Analog Devices Inc**, Wilmington, MA. (617) 937-1428.
Circle No. 344

PLL frequency synthesizer has input frequency of 220 MHz and operates from 3 mA. The PMB2307 PLL frequency synthesizer offers low-power operation for portable applications such as personal communications services, IS-54, Cellular Digital Packet Data, and Global System for Mobile communications. The device has a reference frequency that extends to 50 MHz. The device comes in a TSOP and costs $2.50 (10,000). **Siemens Components Inc, Integrated Circuits Division**, Cupertino, CA. (408) 777-4500.
Circle No. 345



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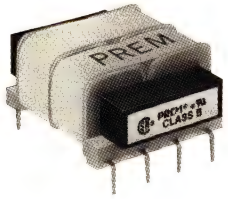
"She said her company's transformers were statistically sampled. But all I could think about were her statistics. Then Rocky, the guy in production, rejected her transformers and she rejected me. Rocky told me to order Prem's 100% final tested transformers direct from the factory next time and skip the middleman…or woman… no matter how good her inventory looked."



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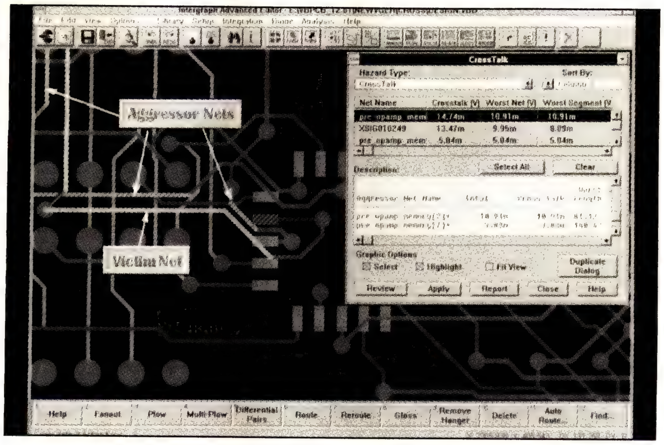
Low-cost Windows-based DSP development tool. Hypersignal for Windows Block-Lite is an abridged version of the company's Hypersignal for Windows Block Diagram product. The $895 package targets teaching and learning DSP fundamentals; however, it also suits OEM applications and works with a variety of plug-in DSP hardware boards. To use the tool, you select function blocks and connect them graphically. The tool has libraries of functions for both simulation applications, such as graphical algorithm development, and for real-time DSP applications. **Hyperception**, Dallas, TX. (214) 343-8525.
Circle No. 402



▲Board-layout software includes signal-integrity functions. The VeriBest PCB 14.0 tool for automatic design of pc boards and multichip modules lets you assign a variety of high-speed design rules to nets and net classes. The software adheres to the rules and notifies you of violations. It provides instant updates for net delay, length, parallelism, and crosstalk as you modify a net. A 2-D field solver characterizes nets. The software also provides automatic and interactive support for blind and buried vias. Price is $30,000. Users of version 12 will receive free upgrades. **Intergraph Corp**, Huntsville, AL. (800) 837-4237.
Circle No. 403

Timing-analysis tool accommodates customized delay calculations. Motive Version 4.3 has a subset of the Verilog application-programming interface that lets you integrate custom delay calculators. The tool's new nonlinear delay-modeling capability supports 1- or 2-D variable dependency. You can represent each delay path in a device as a function of input-edge transition delay, output load, or both. The tool runs on Unix systems, and prices start at $24,000. **Quad Design**, Camarillo, CA. (805) 988-8250.
Circle No. 404

Tools link CAD/CAE, test, production, repair, and inventory systems. The C-Link tools enable a common link of design and manufacturing databases. The tools also perform functions such

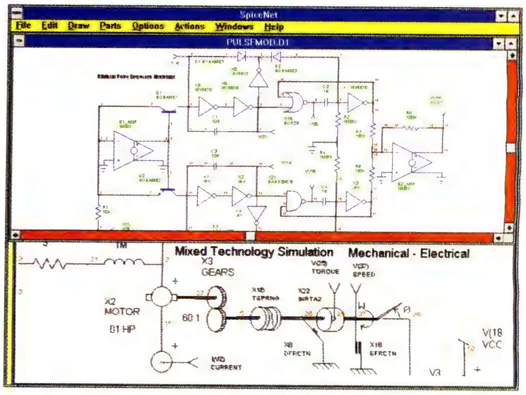
New HDL Based on C

Intusoft has introduced the FIRST and ONLY analog and mixed signal HDL (Hardware Description Language) that runs under Windows, is non-proprietary, and is based on C. The language is called XDL, for eXtended Description Language, and is based on the publicly available XSPICE program from the Georgia Institute of Technology.

XDL models are like traditional SPICE models, except they are created using C subroutines. New models are developed using the Intusoft Code Model Software Development Kit, or CMSDK. The models are portable between any simulator that understands XDL including Intusoft's powerful SPICE 3 based simulator IsSpice4. Here are some of the benefits of XDL and the CMSDK:

- Add new models to SPICE in Days instead of Months
- Easy to use; CMSDK shields you from internal SPICE intricacies
- Create simple or complex models including: analog, digital, mixed mode, and "mixed domain" (mechanical, radiation, array processing, RF, system-level transfer functions, etc.)
- Interface other software programs & simulators to SPICE
- Mix hardware test and measurements with IsSpice4 simulations
- XDL is superior to current AHDL alternatives:
  - Unlimited state variables, nodal connections and parameters
  - Models can be encrypted or copy protected for distribution
  - Easier to adapt existing SPICE models
  - Greater flexibility; Only limited by what you can do in C
- Affordable prices SIMULATOR and CMSDK < $5500

An analog and mixed signal HDL that's easy to use, doesn't force me to learn a new language, or new tools, and I can afford it? Can't Be!!



New HDL enables Mixed Mode and "Mixed Domain" Mechanical-Electrical Simulations

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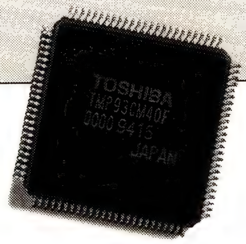
as extracting data from CAD systems to develop circuit descriptions for board testing. They can create the documentation for constructing in-circuit, functional, bed-of-nails fixtures. They also provide programs for pick-and-place machines and parts lists, specifications, and schematics for repairs. The basic C-Link module costs $7500 to $12,500 per seat. Additional modules for test, production, and repair cost $7000 to $20,000 per seat. **CAE Technologies Inc**, Concord, CA. (510) 603-8650.
Circle No. 405

All-technology design and analysis tool. ALLTED lets you use the schematic design and analysis methods used in electronic design for hydraulic, pneumatic, control, and electromagnetic systems. The tool helps you integrate the electronic design of a system with the total system design, including other nonelectronic technologies that the system may use. Typical analysis capabilities include steady state, transient, frequency, spectral (Fourier), Monte Carlo, multivariant component analysis, sensitivity, worst case, and optimal tolerance assignment. From $1495 to $7990. **Tatum Labs Inc**, Ann Arbor, MI. (313) 663-8810.
Circle No. 406

System-emulation tool offers real-time operation to 50 MHz. The enhanced System Explorer has new software and hardware to offer a complete rapid prototyping system. The reprogrammable board-level architecture accommodates reprogrammable field-programmable gate arrays (FPGAs) from Altera, AT&T, and Xilinx, letting you choose the architecture that best fits your requirements. You can also use DSPs, µPs, RAMs, ROMs, PLDs, and real-time interfaces to create a prototype system. The software accepts post-synthesized Verilog or VHDL that represents an ASIC and automatically partitions it into multiple FPGAs. Prices start at $40,000. **Aptix Corp**, San Jose, CA. (408) 428-6200. **Circle No. 407**

Software simulates EMC emissions before you build a product. The Compliance electromagnetic-compatibility (EMC) simulator calculates radiated fields due to systems of pc boards and common-mode currents on cables and enclosures. The tool lets you simulate radiated electric and magnetic fields from electronic systems, including multiple pc boards inside an enclosure with internal and external cabling. The tool fully integrates into the com-



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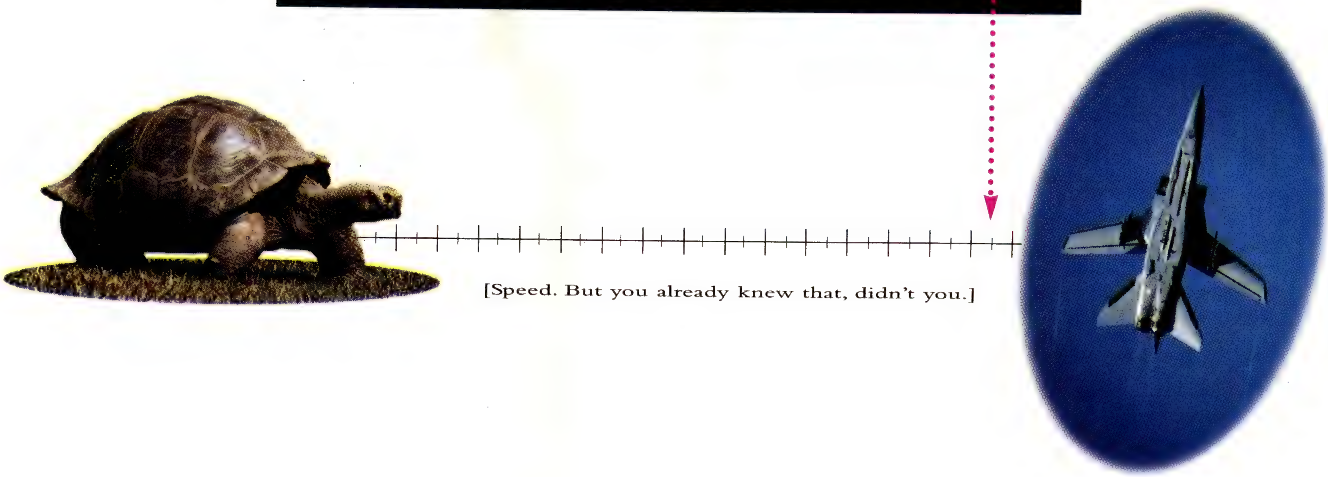

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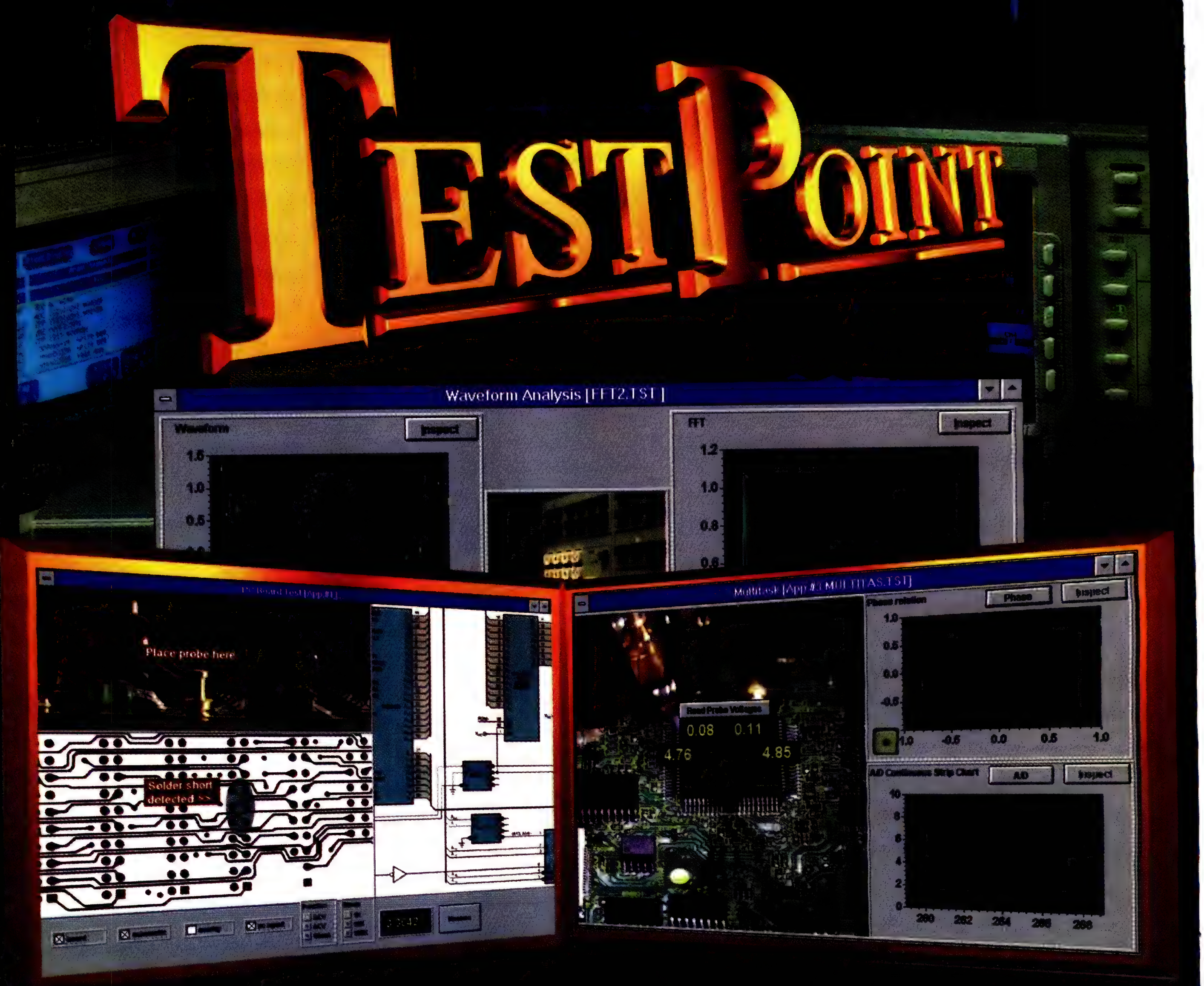

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CIRCLE NO. 125

pany's other signal-integrity tools and costs $49,500. A version for board-level radiation only costs $28,500. **Quantic Laboratories Inc**, Winnipeg, MB, Canada. (204) 942-4000.

Circle No. 408

Tool simulates vibration characteristics of pc boards. PCB Vibration Plus models pc boards, components, and lead/solder-joint interconnects. The tool helps you quickly simulate almost any vibration environment without advanced training in finite-element theory. It calculates the first 50 natural frequencies of a pc-board assembly for accurate vibration simulation. The product is an option to the company's PCB Explorer electronic-design-validation system. From $20,000. **Pacific Numerix Corp**, Scottsdale, AZ. (602) 483-6800.

Circle No. 409

Interoperability tools link EDA data between incompatible tools. The DXE Product family provides a comprehensive development environment, including a data model for electronic data, a high-speed electronic-design-automation (EDA)-specific database-management system, and two levels of procedural interface. Prices for off-the-shelf translators start at $2000, and prices for interoperability environments start at $15,000. The products are available for a variety of workstations and PCs. **Engineering Data-Xpress**, San Jose, CA. (408) 243-8786.

Circle No. 410

Schematic-capture and pc-board-design tool provides P-CAD compatibility. TangoPRO Version 3.0 provides file compatibility with the company's recently acquired P-CAD product. The new version also lets you pass attributes attached to components or nets from TangoPRO Schematic to TangoPRO PCB. The software also simplifies the creation and handling of electrical connections during manual routing. Other features include simplified T-routing, optimized connection lines, and productivity features. TangoPRO Schematic costs $995. TangoPRO PCB costs $5950. TangoPRO PCB Lite, a reduced-function version of TangoPRO PCB, includes all the Version 3.0 enhancements and costs $1995. **Accel Technologies Inc**, San Diego, CA. (619) 554-1000.

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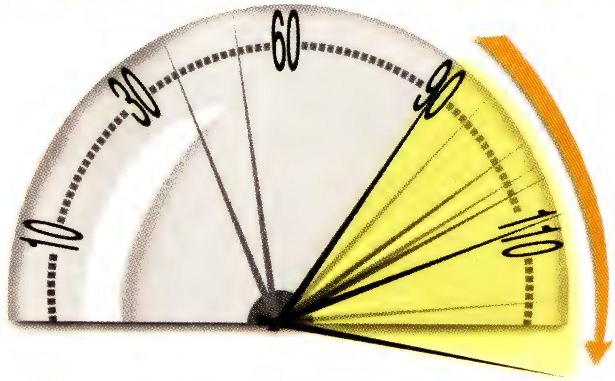

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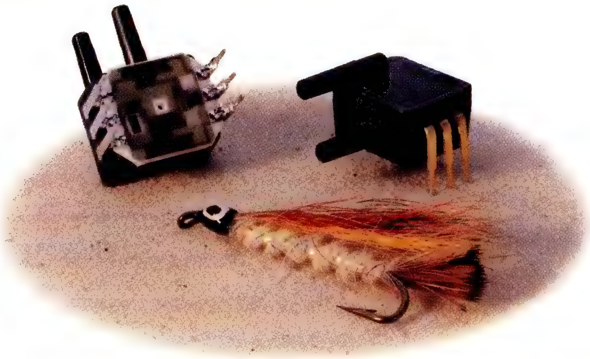

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Spread-spectrum amplifier extends range and reliability of 900-MHz and 2.4-GHz wireless systems. The HyperAmp places maximum transmit power at the antenna, where it is most effective, permitting antenna cable lengths of up to 1000 ft. In both transmit and receive modes, the amplifier eliminates the need for expensive, low-loss, antenna cable. The unit is housed in a weatherproof enclosure suitable for mast-mounting and is powered through the antenna feed cable, eliminating the need for additional power wiring. The 900-MHz amplifier is available in 250-mW to 10W versions; the 2.4-GHz amplifier is available in 100-mW to 10W versions. From $595 to $995. **Hyperlink Technologies Inc**, Boca Raton, FL. (407) 995-2256.

Circle No. 380

Terminal servers add four or eight 115-kbaud intelligent serial ports via the SCSI port. Intended for adding terminals to Unix-based-workstation systems, the SCSI Terminal Servers are available in the four-port ST-1400 model ($795) and the eight-port ST-1800 model ($895). The eight-port ST-1800+ ($995) includes a parallel port for printer connections. The terminal servers contain flash EPROM for easy firmware upgrades in the field. **Central Data Corp**, Champaign, IL. (217) 359-8010.

Circle No. 381

PCMCIA Type III card offers 175 Mbytes of flash mass storage. The Flashdisk cards are available in 80-, 110-, or 175-Mbyte capacities, and compression technology lets you double these capacities. They have an MTBF of 500,000 hours and an operating shock rating of 1000g, and they consume <5% of the power required by 1.8- or 2.5-in. rotating disk drives. The cards cost $1760 (OEM) for 80 Mbytes, $2172 (OEM) for 110 Mbytes, and $3245 (OEM) for 175 Mbytes. **SunDisk Corp**, Santa Clara, CA. (408) 562-0500.

Circle No. 382

Super VGA monitor suits harsh industrial environments. The 9403 Industrial Super VGA Monitor has a 14-in. display with a NEMA 4/NEMA 12 sealed front panel. The rack- or panel-mounted monitor includes a 32-key data-entry or -control keypad, 20 function keys, and a front-panel access plug for an external IBM-compatible keyboard. A programmable keyboard interface merges all keyboard and keypad signals into one output signal, which acts like a standard IBM-compatible keyboard. A Windows 3.1-compatible touchscreen option is also available. The monitor costs $2350. **Xycom**, Saline, MI. (313) 429-4971.

Circle No. 383

Notebook computer based on microSPARC II processor. The SPARCbook 3XP has a SPECint92 rating of 64 and a SPECfp92 rating of 54.6. The system also has a Weitek Power 9100 graphics controller, providing up to 25% performance improvement on some graphics-intensive applications. Battery capacity provides 1 to 2 hours of continuous use, depending on power-management options. The 7-lb workstation includes a color thin-film-transistor screen, a removable 2.5-in. disk drive, PCMCIA slots, a 2-Mbyte VRAM frame buffer, 16-bit audio, Ethernet, and on-board integrated-services digital-network and fax-modem capabilities. The system comes with Solaris 1 or 2 operating environments and costs $11,950. **Tadpole Technology Inc**, Austin, TX. (512) 219-2200.

Circle No. 384

Parallel-processing development environment runs under Windows 3.1. The CNAPS/PC development environment for the company's CNAPS/PC board includes a parallel C compiler, assembly language, an assembler, a debugger, and libraries for common functions that can be called from C programs. The CNAPS/PC board uses a parallel architecture that contains 16 or 64 processors on a chip and up to 128 processors on a board. The board suits parallel-processing applications, such as real-time image processing and neural networks. The development environment costs $9995. **Adaptive Solutions**, Beaverton, OR. (503) 690-1236. **Circle No. 385**

Flash PCMCIA memory cards provide 1.8- to 40-Mbyte capacities. Motorola is providing Flashdisk memory cards through an OEM agreement with SunDisk. The integrated flash controller is compatible with any operating system that supports IDE disk drives. The solid-state memory cards can withstand 1000g shocks and sustained vibrations of up to 15g. They have suggested list prices from $190 for 1.8 Mbytes to $1395 for 40 Mbytes. **Motorola Microprocessor and Memory Technologies Group**, Austin, TX. (512) 933-6700.

Circle No. 386

Hardware and software create a low-bit-rate digital connection between two analog interfaces. The InvisiLink card and software accept simultaneous PCM samples and a digital bit stream, automatically compress the data, pass it through an analog link, and decompress the data. The hardware and software cost depends on the hardware platform; typical cost is $500 (1000). **DSP Software Engineering Inc**, Bedford, MA. (617) 275-3733.

Circle No. 387

Ergonomic keyboard has independently adjustable halves for comfortable positioning. The Ergo-Master PC-compatible keyboard is designed for users performing intensive, long-duration typing duties. According to the company, no single typing position is ergonomic if you maintain it for an extended period of time. The new keyboard lets you periodically adjust typing position to maintain comfort. $495. **Genovation Inc**, Irvine, CA. (714) 833-3355. **Circle No. 388**

SPARCstation 20-compatible systems use SuperSPARC II processor. The SuperCOMPstation 20S Series workstations use the 75-MHz SuperSPARC II processor with performance ratings of 125 SPECint 92 and 121 SPECfp92 for each CPU. An entry-level desktop configuration, the model 20S/71, costs $16,070, a 20-in. color monitor, two MBus slots, four 32/64-bit SBus slots, 32 Mbytes of RAM, a 520-Mbyte hard-disk drive, Turbo GX graphics, and 16-bit audio. A dual-processor 20S/712-MP system is also available. **Tatung Science & Technology Inc**, Milpitas, CA. (408) 383-0988.

Circle No. 389

Remote-access unit provides secure connection with up to 16 remote devices. The SAS-7016 provides five levels of optional security for connecting to other devices at a remote site via a modem. The 16-port system costs $899. **Gilltro-Electronics Inc**, Santa Clara, CA. (408) 727-6422.

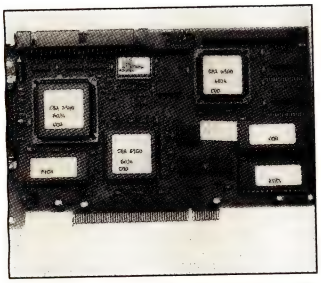
Circle No. 390

64-bit graphics card gives video acceleration for Windows. The Graphics-Engine Ultra 64 AV, a 2-Mbyte VRAM-based graphics card for the Peripheral Component Interconnect local bus, provides full-motion video and true-color graphics. The graphics board is based on S3's Vision968 graphics accelerator. The 2-Mbyte version costs $365, and a 4-Mbyte version costs $549. **Actix Systems Inc**, Santa Clara, CA. (408) 986-1625.

Circle No. 391

Force-feedback devices provide realistic feel for simulated environments. The Impulse Engine 1000 provides 1-D force feedback for linear motion and costs $2495. The Impulse Engine 2000 provides a computer-controlled force-feedback joystick for accurate flight simulation and other applications. It costs $4995. The Impulse Engine 3000 provides three-degrees-of-freedom force feedback and costs $7995. The Laparoscopic Impulse Engine is designed for simulating surgical operations, providing realistic feedback forces to a user's hand. It costs $8595. **Immersion Corp**, Santa Clara, CA. (408) 653-1160.

Circle No. 392



SCSI controllers for PCI bus are available in caching and noncaching configurations. The CSA-6500 is a noncaching SCSI controller that comes complete with SCSI cable and a full driver set. List price is $359. The CSA-6520 SCSI controller offers 4 to 64 Mbytes of user-installable cache. List price is $595. **CMD Technology Inc**, Irvine, CA. (714) 454-0800.

Circle No. 393

SPARCstation 20-compatible systems use Ross 100-MHz quad HyperSPARC. The SWS20 and SWS20E are for easy hard-disk upgrades or for adding other SCSI devices. They accommodate up to two internal hard disks, one floppy disk, and an internal CD-ROM drive. A base system costs $3495 and includes a system board, a chassis, and a 150W power supply. The entry-level SWS20E with an integrated-services digital-network interface costs $2995. A system based on the 100-MHz SWS20 HyperSPARC CPU with 32 Mbytes of memory, a 1-Gbyte hard-disk drive, and a 17-in. color monitor costs $10,495. A similar configuration based on the SWS20E costs $9995. **Integrix Inc**, Newbury Park, CA. (805) 375-1055.

Circle No. 394

Mouse works on any surface. The LifeTime Mouse uses two feet with optomechanical technology instead of a ball mechanism. According to the company, the mechanism works on any surface and has greater accuracy, reliability, and durability than single-ball designs. The mouse comes with a Microsoft-compatible driver and a limited lifetime warranty. Suggested retail price is $49. **Key Tronic Corp**, Spokane, WA. (509) 928-8000.

Circle No. 395

Software removes unwanted or unneeded programs under Windows to conserve disk space. CleanSweep finds and removes outdated, unnecessary, and unwanted applications, files, or system components. The software locates files associated with unwanted programs and lets you choose whether to remove them. It finds backup, temporary, archived, help, bit-map, and lost cluster files. You can also eliminate unneeded graphics drivers, fonts, wallpapers, and other files. By default, the software automatically compresses and archives all uninstalled files, making it easy to restore them. A perpetual log tracks all actions that CleanSweep performs. $39 to $49. **Quarterdeck Office Systems Inc**, Santa Monica, CA. (310) 392-9851.

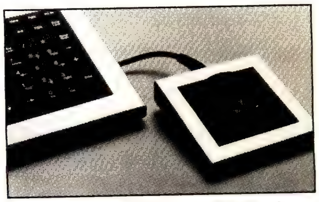
Circle No. 396

Parallel-processing servers provide variety of price/performance options. The K20000 parallel server accommodates >4000 processors. Prices start at $339,000. Other versions include the K2000 with prices starting at $135,000, the K200 with prices starting at $70,000, and the K2 with prices starting at $25,000. **Tandem Computers Inc**, Cupertino, CA. (408) 285-6000.

Circle No. 397

SCSI-2 board for Sun workstations includes boot support. The PT-SBS440A module is a 20-Mbyte/sec Wide/Fast SCSI board for use in Sun and Sun-compatible workstations. Boot support lets you designate a SCSI device as the mass-storage peripheral for the workstation to use when loading the operating system after you power up or reset the system. The board comes with a plug-and-play driver and installation software for both *SunOS* 4.1.x and Solaris 2.x. $995. **Performance Computer**, Rochester, NY. (716) 256-0200.

Circle No. 398



Three-button pointing device for industrial applications provides sealing and long life. HulaPoint is virtually unbreakable and meets or exceeds NEMA 4x specifications. The device senses the position of sealed magnets to determine the pointing input. According to the company, the device offers the flexibility of a joystick and the functionality of a mouse. It comes with either the Microsoft PS/2 or Logitech protocol and is available as a desktop pointing device, a panel-mounted pointing device, or an OEM configuration. The desktop model costs $249. **Texas Industrial Peripherals**, Austin, TX. (512) 837-0283.

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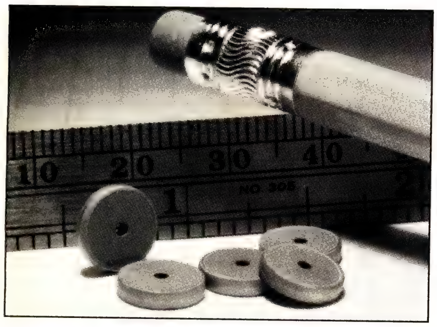
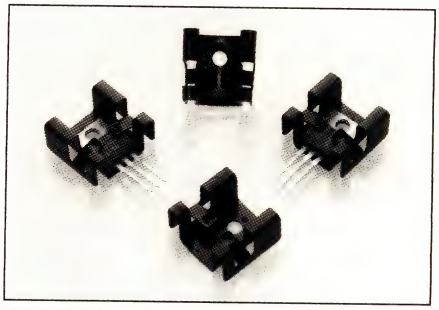
Polypropylene-film capacitors offer high-voltage, high-current capability. The axial-lead PWM Series and rectangular-box-with-radial-lead PPB Series of polypropylene-film capacitors suit applications such as insulated-gate bipolar-transistor snubber circuits, silicon-controlled-rectifier commutation, uninterruptible-power-supply circuits, and power inverters. The capacitors come in voltage ranges up to 2000V dc and dv/dt ranges of 250 to 750 V/μsec for the PWM Series and 170 to 6200 V/μsec for the PPB Series. Capacitance ranges are 0.47 to 1.5 μF for the PWM Series and 0.0068 to 6.8 μF for the PPB Series. Prices for the PWM Series start at $1.10 (1000), and prices for the PPB Series start at $0.43 (1000). **Illinois Capacitor Inc**, Lincolnwood, IL. (708) 675-1760. **Circle No. 428**



Discoidal chip multilayer ceramic capacitors available with COG, X7R, and Z5U dielectrics. The discoidal capacitors are suited for direct mounting into filters, bulkheads, and hybrid circuits. Capacitance ranges are from 82 pF to 390 nF in COG dielectric, 2.2 nF to 3.9 μF in X7R dielectric, and 4.7 nF to 4.7 μF in Z5U dielectric. Voltage ranges are 500Vdc to 1 kV. The outside diameter of the capacitors ranges from 3 to 16 mm and the center-hole diameter ranges from 0.6 to 2 mm. Maximum thickness is 3 mm. The capacitors cost from $0.94 to $9.40 (1000). **Cal-Chip Electronics Inc**, Warminster, PA. (215) 672-5500. **Circle No. 429**

300- to 650-MHz clock oscillators have <5-psec output jitter. The M100 clock oscillator family is available in 300- to 650-MHz frequencies and provides complementary ECL/positive-ECL clock outputs. The M200/210 family of frequency multipliers has an output frequency range of 300 to 650 MHz. The multiplication factor ranges from 2 to 255. Frequency multipliers suit use in systems requiring high-frequency, phase-aligned, synchronous clocks derived from a lower frequency master-clock source. Output-to-reference skew is 1.5 nsec. The M300 family of VCXOs offers an output frequency centered at 622.0800 MHz for use in synchronous-optical-network systems. The devices come in 24-pin DIP packages. Typical prices range from $143 (100) to $178 (100). **Micro Networks Corp**, Worcester, MA. (508) 852-5400. **Circle No. 430**

Rocker switches snap into standard 22×30-mm panel cutout. The Series 8090 intermediate rocker switches are available with paddle or rocker actuators and in a range of actuator and bezel colors The devices have 0.25-in.-wide, tin-plated, quick-connect terminals. The switches are UL-recognized, CSA-certified, and VDE-approved. They are rated for 16A at 125V ac, 10A at 250V ac (UL and CSA), 16A at 250V ac (VDE), and 16A at 28V dc. Configurations include single or double pole, single throw. $0.91 (1000). **Eaton Corp, Aerospace and Commercial Controls**, Milwaukee, WI. (414) 449-7326. **Circle No. 431**



TO-220 heat sinks mount horizontally or vertically. The 275 Series heat sinks have stress-free locking tabs that provide fast installation and removal. The tabs ensure reliable device-to-heat-sink surface contact. The heat sinks are available in a 0.75-in.-high version and a 1.375-in.-high version. From $0.146 (1000). **Wakefield Engineering Inc**, Wakefield, MA. (617) 245-5900. **Circle No. 432**

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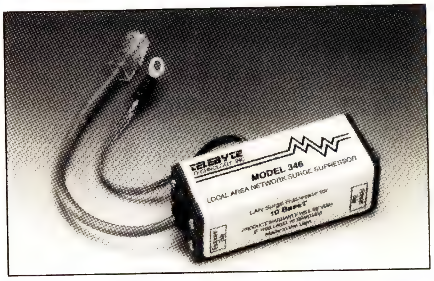
CIRCLE NO. 92

160-pin connector for VME64. The har-bus64 160-pin connector has 64 contacts installed in two new rows, designated row z (adjacent to row a) and row d (adjacent to row c). The connector provides backward compatibility with 96-pin Eurocard connectors. You can use the new connectors to add more I/O to the P2/J2 connector and additional grounds for improved high-speed performance of the P1/J1 connector. The connectors cost $30 per mated pair. **Harting Electronik Inc**, Hoffman Estates, IL. (708) 519-7700. **Circle No. 433**

High-voltage capacitors feature dry construction to avoid leakage. The 430PHV capacitor family is available in 0.001- to 1-µF values and up to 15-kV-dc ratings. The self-healing capacitors have a tape-wrapped, epoxy-end-pour, flame-retardant, moisture-shielding construction. Typical applications include voltage-multiplier circuits for electrostatic dust collectors and high-voltage power supplies. Average price is $0.72 (1000). **Dearborn Electronics Inc**, Longwood, FL. (407) 695-6562. **Circle No. 434**



10BaseT Ethernet surge protector for use with twisted-pair cabling. The Model 346 surge protector clamps voltages to 7V peak, responding in <1 nsec to overvoltage conditions. According to the company, the device offers complete protection for 10BaseT adapter cards used in LANs from electrostatic discharge, transient pulses, and lightning strikes. $65. **Telebyte Technology Inc**, Greenlawn, NY. (516) 423-3232. **Circle No. 435**

Miniature surface-mount RF transformer operates from 1.5 to 500 MHz. The 0.16×0.16×0.16-in. TC1-1 RF transformer suits pick-and-place machines. The transformer provides primary-to-secondary dc isolation and suits balanced-to-unbalanced transformer applications. $4.95. **Mini-Circuits**, Brooklyn, NY. (718) 934-4500. **Circle No. 436**

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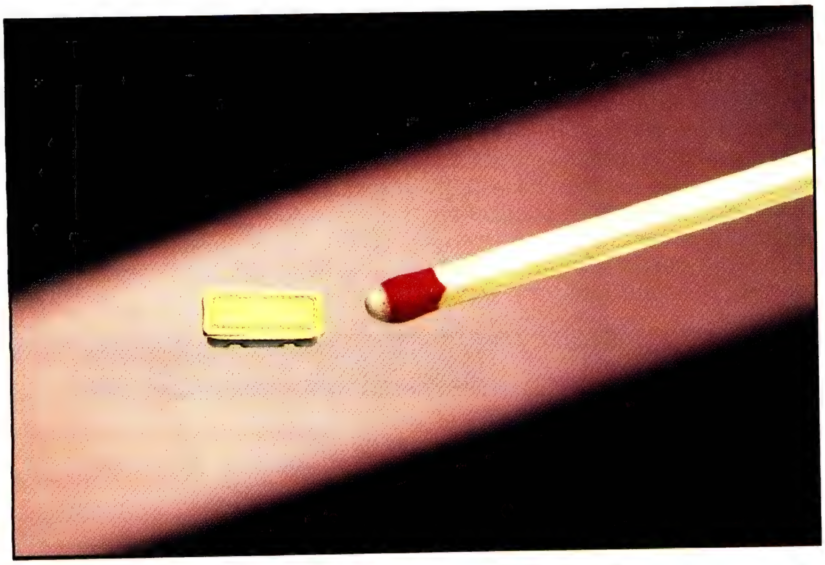

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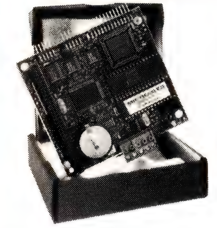

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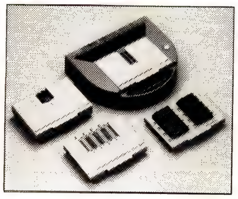

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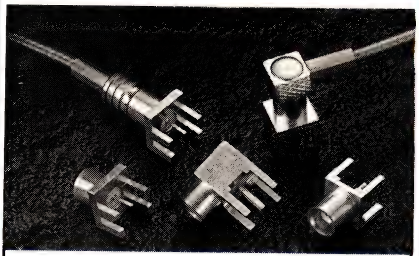

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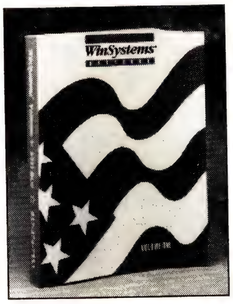

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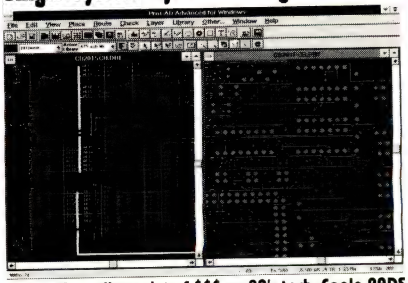
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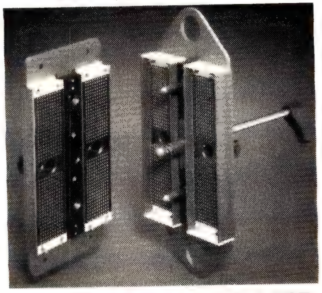

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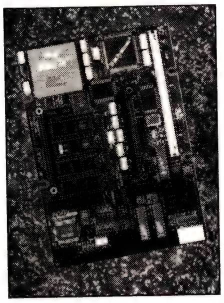

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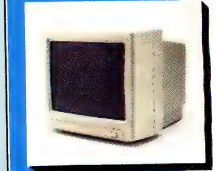

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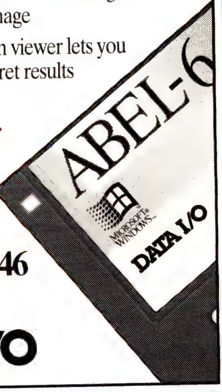

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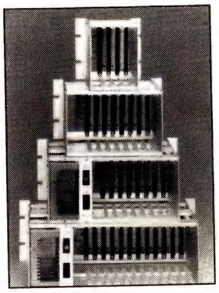

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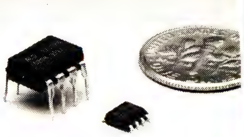

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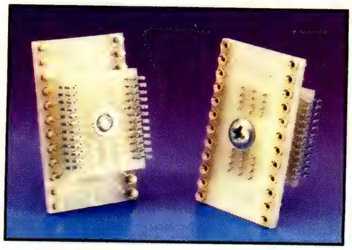

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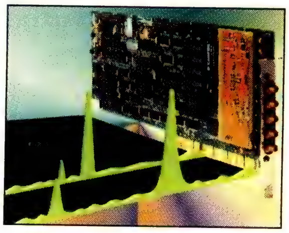

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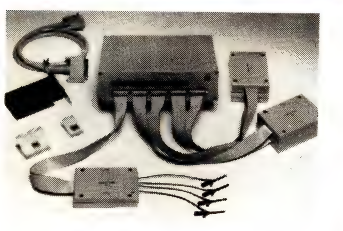

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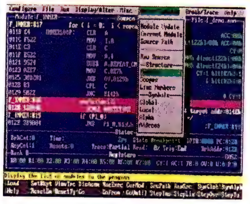

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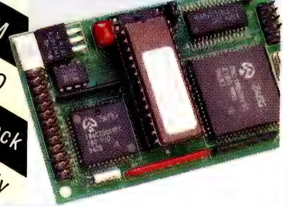

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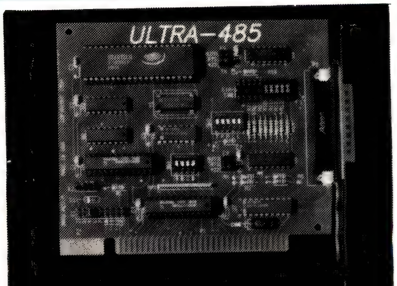

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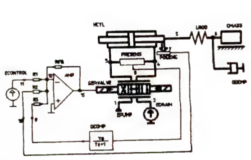

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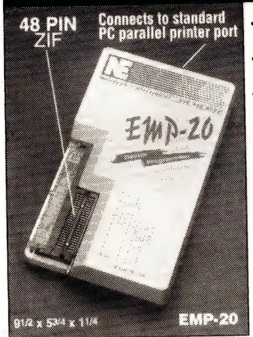

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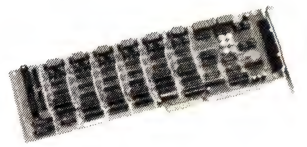

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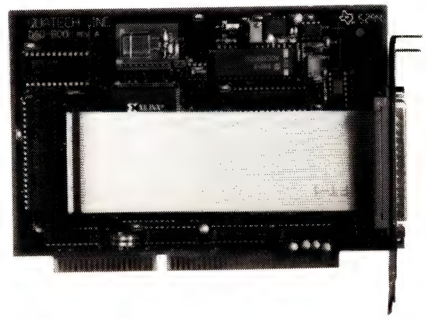

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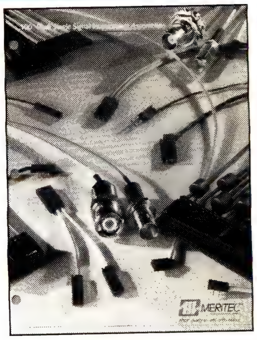

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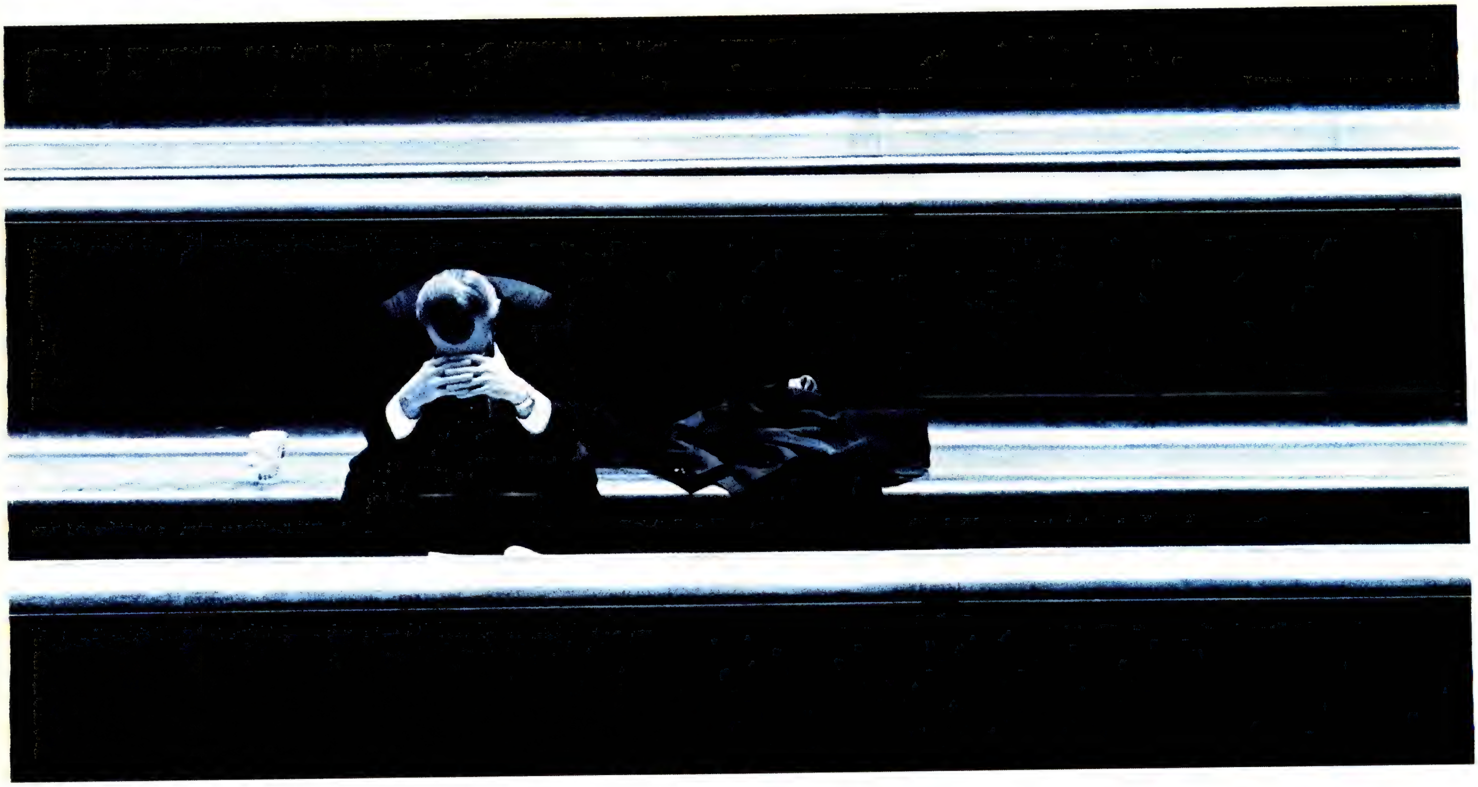

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CIRCLE NO. 138

JACK GANSSLE,
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In µPs, smaller is sometimes better

Sssh! Listen to the hum. That's the sound of the incessant information processing that subtly surrounds us, which keeps us warm, washes our clothes, cycles water to the lawn, and generally makes life a little more tolerable. It's so quiet and keeps such a low profile that even embedded designers forget how much data processing dominates our lives. Sure, we rail at the banks' mainframes for messing up a credit report while the fridge kicks into auto-defrost and the microwave spits out another meal.

The average house has some 40 to 50 µPs embedded into appliances. There's neither central control nor networking: Each quietly goes about its business, ably taking care of just one little function—distributed processing at its best.

Billions and billions of 4- to 16-bit µPs find their way into our lives every year, yet we hear primarily about the 10s of millions that reside on our desktops. The market for RISC and high-end CISC is a 0% market by comparison, yet this 0% market gets all the glory.

> **Derivatives of some of the earlier embedded CPUs still dominate the market.**

Now, I'll never give up that 1-zillion-MIPS little beauty I'm hunched over at the moment. We all crave more horsepower to handle Microsoft's latest cycle-consuming application. I'm just getting tired of 32-bit hype for embedded applications. Perhaps that 747 display controller or laser printer needs the power. Surely, though, most applications do not.

Derivatives of some of the earliest embedded CPUs still dominate the market. Motorola's 6805 is a scaled-up 6800 that competed with the 8080 back in the embedded Dark Ages. The 8051 and its variants are based on the almost-20-year-old 8048. The 8051s, in particular, have been the glue of this industry, corresponding to the analog world's old 741 op amp or the 555 timer. You find them *everywhere*. Their price, availability, and onboard EPROM make them the natural choice for applications ranging from those requiring just a hint of computing power to fairly substantial controllers with limited user interfaces.

I'm fascinated with Microchip's PIC16/17 processors, which seem to be squeezing into a lot of low-end applications. These are cool parts. The smaller members of the family offer minimal computational capability, which is ideal for simple, cost-sensitive systems. Higher end versions are well-suited for more complicated control applications.

Designers view these CPUs as something other than computers. "Oh yeah, we tossed in a couple of PIC16s to handle the microswitches," the engineer relates, as if the part were nothing more than a PAL. This is a bit different from the look you get from the haggard designer trying to ship a 68030-based controller. The microcontroller is easy to use simply because it is stuffed into easy applications.

LA Gear sells sneakers that blink an LED when you walk. A PIC16C5x powers these for months or years without the need to replace the battery. Scientists tag animals in the wild with expendable subcutaneous tracking devices powered by these parts. Household appliances also depend on PIC variants.

A friend developing instruments based on a 32-bit CPU discovered that his PLDs don't always properly recover from brownout conditions. He stuffed a $2 Microchip controller onto the board to sequence the PLD's reset signals properly, ensuring recovery from low-voltage spikes. The part costs virtually nothing, requires no more than a handful of lines of code, and occupies the board space of a small DIP. Though it may seem weird to use a full computer for this trivial function, it's cheaper than a PAL.

It's not that there's anything wrong with PALs: Nothing is faster or better at handling complex combinatorial logic. Modern superfast versions are cheap ($12 in singles for a 7-nsec 22V10), easy-to-use, and reprogrammable—a great savior of designs that aren't quite right. PALs, though, are terrible at handling anything other than simple sequential

PHOTOGRAPHY / HOWARD DAVIS

logic. They have a limited number of registers and clocking options, meaning you can't use them for complicated decision making. PLDs are better, but when speed is not critical, a computer chip might be the simplest way to go.

As the industry matures, many parts we depend on become obsolete. One acquaintance found the UART on which his company depended was no longer available. He built a replacement in a PIC16C74, which was pin-compatible with the original UART, saving the company expensive redesigns.

As the price of microcontrollers slides toward zero, more people get by without any sort of tools.

Part of Microchip's success comes from the aggressive use of one-time-programmable (OTP) memory in all of the company's processors. Motorola and others make good use of OTP as well. Now, a number of programmable PLDs are also available in OTP versions. It's a sure bet that this technology will become ever more important in the future.

OTP memory is simply good, old-fashioned EPROM but without an erasure window. That small quartz opening typical of EPROMs and many PLDs is expensive to manufacture. You can program the memory on any conventional device programmer, but, because OTP lacks a window, you can never erase the memory. When it's time to change the code, you toss the part out.

Many years ago, Intel sold OTP versions of EPROMs, but they never caught on. A system that uses discrete-memory devices, such as RAM and ROM, has intrinsically higher costs than those based on a microcontroller. In a system with $100 worth of parts, using erasable EPROMs, which are very forgiving of mistakes, will cost only $1 or $2 extra.

The dynamics are a bit different with a minimal system. If a $2 part contains an entire computer, adding a $1 window is a huge cost hit. OTP starts to make sense, assuming your code is stable.

The code *can* be cast in concrete in small applications because the entire program might require only 10s to 100s of statements. I plead guilty to causing one or two disasters seeming to have more bugs than lines of code. However, once you debug and thoroughly test a 10- to 100-statement program, it holds little chance of containing an obscure bug. In this case, going with OTP invokes little risk.

You can't pick up a magazine without reading about time to market. Managers want to shrink development times to zero. One obvious solution is to replace masked ROMs with their OTP equivalents because producing a processor with the code permanently engraved in a metalization layer takes months and suffers from the same risk factors as does OTP. The masked part might be a bit cheaper in high volumes, but this price advantage doesn't help much if you can't ship while waiting for parts to arrive.

Part of the art of managing a business is to preserve your options as long as possible. Stuff happens. You can't predict everything. Given options, you have the flexibility to adapt to problems and changing markets, even at the last minute. For example, some companies ship multiple versions of a product, differing only in the code. An OTP part lets them make a last-minute decision on the production floor, about how many of a particular widget to build. If you have $500,000 tied up in inventory of masked parts, your options are awfully limited.

Part of the 8051's success came from the wide variety of parts available. You could get EPROM or masked versions of the same part. Low-volume applications always took advantage of the EPROM version. OTP significantly reduces the costs of the parts, even when you are building only a handful.

Are tools necessary?

Microcontrollers pose special challenges for designers. Because nothing more than I/O pins bind a typical part, it's hard to see what's going on inside. Nohau, Metalink, and others make it their business to produce tools to peer inside these devices, giving the user a "window" into a usually closed system.

Now, though, as the price of controllers slides toward zero and, hence, only truly minimal applications use the devices, more people get by without any sort of tools. Although it's hard to condone shortchanging efficiency to save a few dollars, it's equally hard to argue that a 50-line program needs much help. You can probably eyeball it to perfection on the first or second iteration. Again, "appropriate technology" is the watchword. A 5000-line assembly-language program on a 6805 will force you to buy decent debuggers and, I hope, a C compiler.

You can often bring up a microcontroller-based design without a logic analyzer, because there's no bus to watch. Some people even replace the scope with nothing more than a logic probe.

An army of tool vendors supplies low-cost tools to handle the problems that microcontrollers pose. Using any controller gives you far more options than would embedding a SPARC processor into your system. Some companies cater especially to the low end. Most do a great job, despite the low cost. I recently looked at Byte Craft's array of compilers for microcontrollers from Microchip, Motorola, and National. Despite the limited address spaces of some of these parts, a decent C compiler can produce efficient code for them.

Working in a shop that mostly uses midrange processors, I'm amazed at the amount of fancy equipment on which we rely and am sometimes a bit wistful for those days of operating out of a garage with not much more than a soldering iron, a logic probe, and a thinking cap. Clearly, the vibrant action in the controller market means that even small, undercapitalized—or uncapitalized—businesses still can introduce competitive products. EDN

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Jack Ganssle is the president of Softaid, a vendor of emulators and other embedded-systems tools. You can contact him via Internet: jack@softaid.net. Or send mail to Softaid, 8310 Guilford Rd, Columbia, MD 21046.

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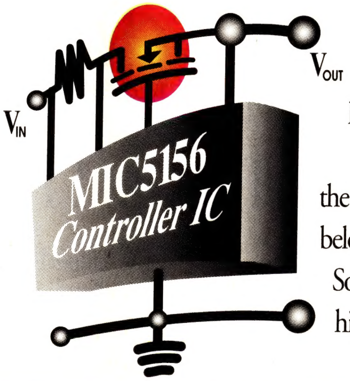

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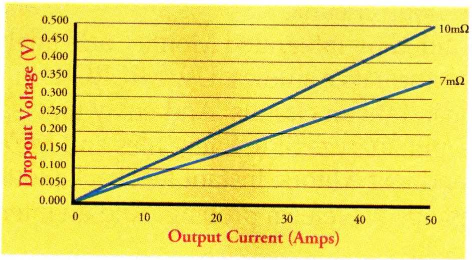

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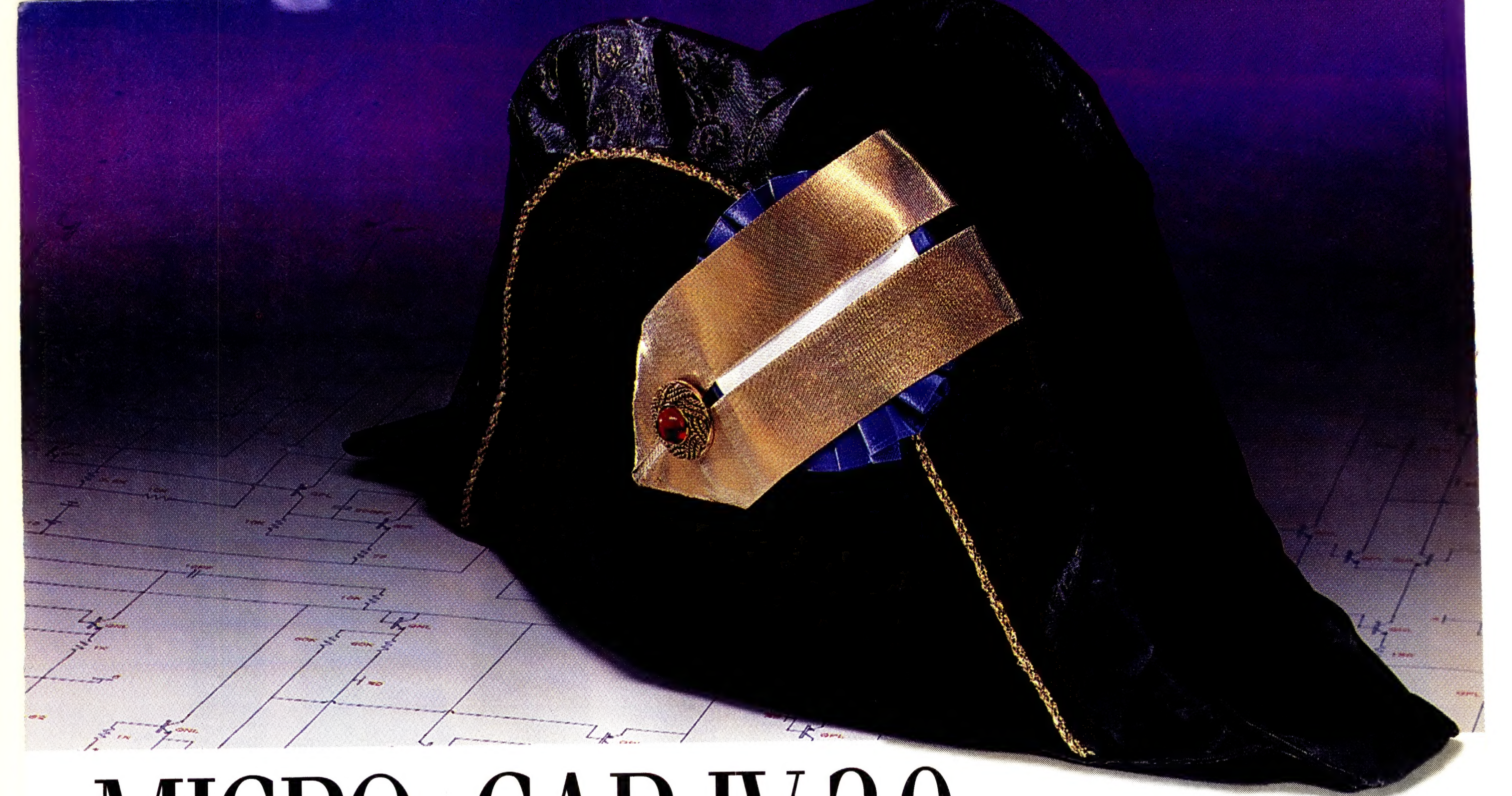

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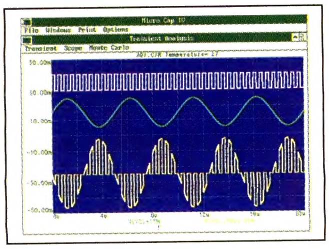

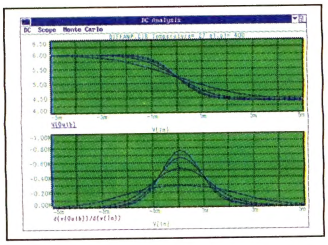

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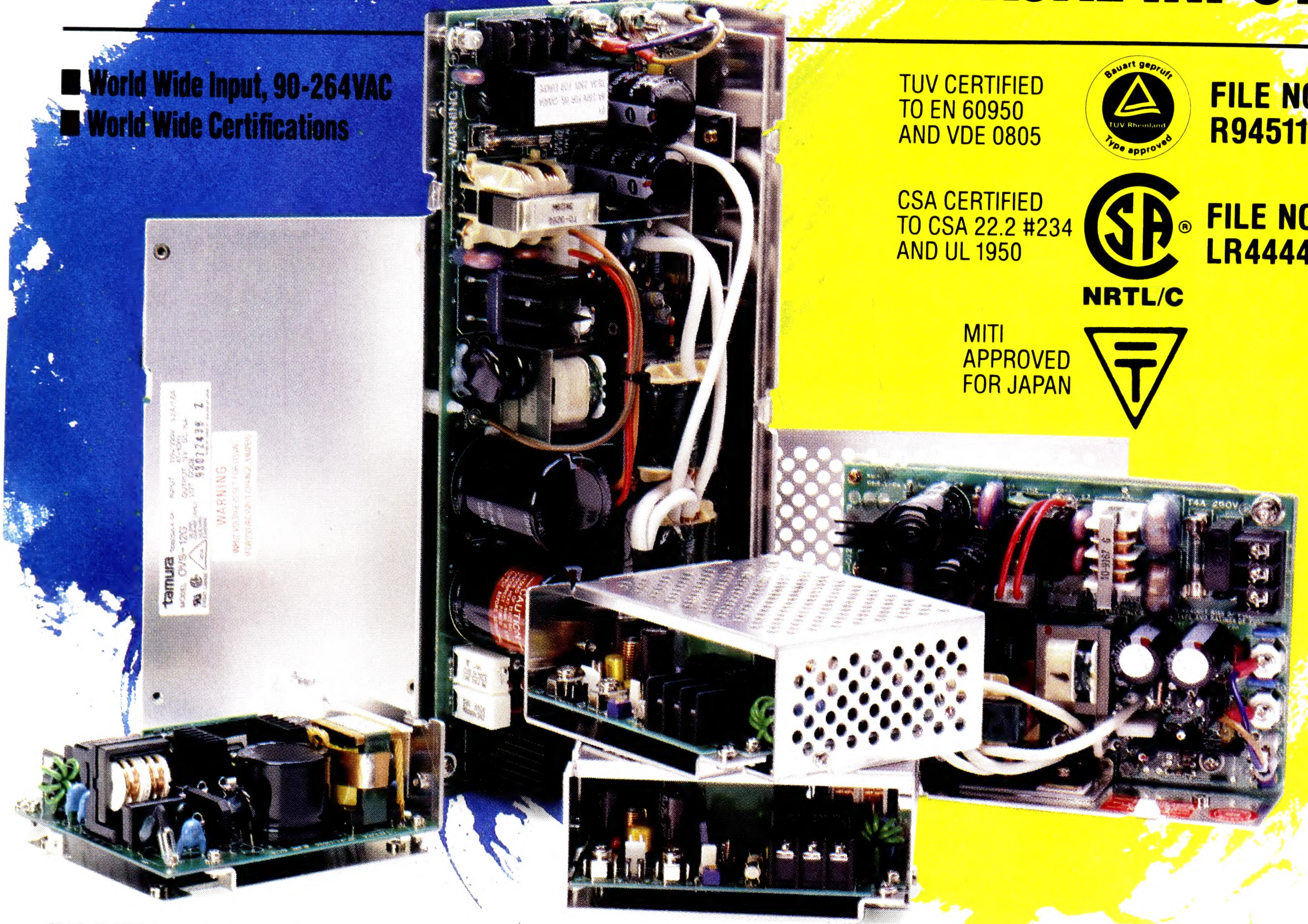

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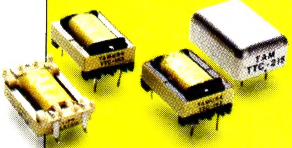

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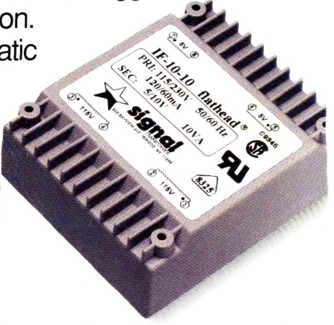

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